Royal Horticultural Society

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AHDB HORTICULTURE

Horticultural Fellowship Awards

Final Report

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:	Final report, June 2017
Previous report:	Annual report, June 2016
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 (***Report Author***)
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):	June 2017

DISCLAIMER

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

Head of Horticulture & Environmental Science

Royal Horticultural Society

Signature .... Date ..25/06/17......................................

[Name]

[Position]

[Organisation]

Signature .... Date ....

Report authorised by:

[Name]

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[Organisation]

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CONTENTS

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 2016	November 2016	N/A
Identification of knowledge gaps, written proposals presented for spin-off funding opportunities	July 2017	On-going – these are to be taken forward by the project steering group	N/A
Presentation of information to a variety of audiences (grower meetings, scientific conferences etc.)	July 2017	April 2017 (Appendix 1, Table A)	N/A
Present findings to RHS Science committee, AHDB studentship conference & appropriate staff seminars at RHS, AHDB, UoR etc.	June 2017	April 2017 (Appendix 1, Table A)	N/A
Scientific publication, AHDB report, articles in RHS publications and general gardening press.	July 2017	On-going (Appendix 1, Table A and see below)	N/A
Display at RHS Chelsea flower show (highlights of the project)	May 2017	N/A trainee to leave April 2017	
To begin collaborative research project	July 2017	N/A trainee to leave April 2017	

Summary of Progress

In the year since the last report, the fellowship has explored the impact of different growing medium types on nutrient loss and nutrient use efficiency in HONS production. The work has built on knowledge acquired over the last 4 years and has been designed to inform growers about how the switch from peat-based to blended peat-reduced growing medium types might be impacting on both fertilizer use efficiency and the quality of nursery discharge water. The trainee, GrB has continued to build her profile within the industry through dissemination of preliminary results at technical workshops (Appendix 1, table A). A significant achievement was the publication of a comprehensive review in the international, peer reviewed scientific journal *Scientia Horticulturae*. This paper describes the current opportunities and challenges facing the industry with regard to finding environmentally sustainable growing medium options (Appendix 2). It represents the culmination of 4.5 years of knowledge acquisition by GrB and is a good demonstration of the expertise acquired in this field by this fellowship project.

Milestones not being reached

All milestones have been reached to date

Do remaining milestones look realistic?

N/A, the project will be ending in April 2017 as the trainee GrB has secured a permanent position within the UK horticulture industry.

Training undertaken

November 2016: 'Royal Society of Biology training course 'on the use of the statistical package R'.

Expertise gained by trainees

Work in the last year has focused on nutrient losses from containerized plants grown with CRF. The project has therefore acquired significant knowledge on the types and action of this type of fertilizer. This has included a review of both the scientific and industry-led literature on the subject.

Other achievements (not originally in the objectives)

- GrB has continued to nurture links with the RHS education department and has produced a growing media themed workshop for secondary school teachers designed to get children more interested in horticulture.
- GrB has been writing regular advisory articles in the RHS publication 'The Garden' magazine, which is circulated to over 470,000 RHS members every month. These articles have drawn on knowledge acquired over the last 4 and a half years and have provided a conduit for communication to a much wider audience.
- Attended AHDB study tour 'Optimising the nutrition of container grown plants' in Belgium (06-07/07/16)

Changes to Project

Are the current objectives still appropriate for the Fellowship?

As stated above, GrB has been offered a position as a technical manager on a UK nursery. The project will therefore be ending in April 2017, as opposed to the original end date of November 2017. The objectives concerned with spin-off projects will be taken forward by other members of the Fellowship steering group.

GROWER SUMMARY

The Impact of different growing medium blends on nutrient loss from container grown hardy ornamental nursery stock (HONS).

Headline

Different growing media impact both on the amount of nutrient lost to the environment and the efficiency of N use within the container

The amount of N and P leached from containers within the first 2 weeks of potting is of a magnitude likely to impact ground water quality

Background

Over the last 5 years, the amount of peat used in professional growing media has reduced and the use of alternatives materials such as coir and wood-based materials have increased (Denny *et al*., 2016). This trend represents a shift from a reliance on almost entirely peat-based container media to those which are based on mixes or blends of two or more different component materials. The materials currently in most common use by UK growing medium manufacturers are peat (63.9%), coir (20.7%), wood-based materials (such as wood fibres), (8.3%), bark (3.6%) and to a lesser extent in recent years, green waste compost (Denny *et al*., 2016). Many HONS growers have now reduced the peat-content of their growing medium formulations, typically by about 30-35% and in a few instances as much as 50% (Denny *et al*., 2016). There is now much evidence to show that growing media based on varying proportions of coir, green waste compost, pine bark and wood fibre can be used successfully to reduce or replace peat whilst maintaining equivalent or better plant quality. However, as shown both earlier in this project (Barrett *et al*., 2014) and elsewhere (Mulholland *et al*., 2015), media based on blends of several material components have physical and chemical properties distinct from traditional peat-based options. This means the way they retain water and nutrients tends to vary, which is likely impacting on both irrigation and fertilizer efficiencies. The majority of HONS in the UK is grown outdoors on nursery beds, which are typically irrigated from above using sprinklers. Any water which misses the pots or drains through the pots (leachate) runs to waste and often into the wider environment. These open systems necessitate the use of polymer coated controlled release fertilizer (CRF) granules, because these products restrict nutrient release, which occurs gradually over a period of months to years. While in principle, CRFs should restrict nutrient leaching from containers during periods of heavy rainfall or irrigation, previous work in peat-based media suggests that depending on rainfall patterns and plant type, nutrient losses from nursery beds may be large (Maher *et al*., 2002). To date few studies have explored the impacts of different growing medium types on nutrient leaching from outdoor HONS production. This represents a significant knowledge gap for growers with regard to how changes in growing medium formulation might firstly be impacting on fertilizer use efficiency and secondly on the nutrient load of nursery discharge waters. The aim of this work was to start to bridge this gap by exploring how different growing medium blends were influencing the amount of nutrients leaching from containers and whether this might lead to any detectable impacts on nitrogen (N) use efficiency.

Summary

There were 4 aims of the work:

1. Measure the amount of N, P and K being leached from outdoor grown HONS.
2. Determine whether different growing medium types influenced the magnitude and pattern of nutrient leaching.
3. Investigate the relative efficiencies of N use (N available for plant uptake vs N lost via leaching) in a range of blended growing media.
4. Determine the contribution of a CRF to nutrient leaching and whether this differed between growing medium types.

Leachate collection devices (LCDs) based on 10l black plastic buckets were constructed to intercept all the leachate produced from a 2l planted container (Image 1a). Six blended growing medium types based on five component materials (coir, garden waste compost, peat, pine bark and wood fibre) were then manufactured with advice from a growing medium manufacturer. The properties of the media were characterised to determine their relative water holding capacity and nutrient content. Nine identical 9cm liners of *Viburnum tinus* ‘French White’ were potted into each of the 6 growing medium types. A combined polymer coated CRF (Plantacote® Top N, 12M, Aglukon) was then dibbled into the container before placement of the liner and infilling (4g/l, 18-6-12). An ‘in-pot’ temperature logger was also placed into the centre of selected containers to monitor the temperatures over the course of the experiment. In addition, 9 plants were potted up into two of the most physically distinct mixes in exactly the same way but without the addition of the CRF. This treatment was designed to determine when the CRF started releasing nutrient and whether this was the same across two physically distinct media types. Plants were then sat atop the LCDs and transferred to a large Mypex covered bed and irrigated with overhead sprinklers (Image 1b).

a)

b)

Image 1. The experimental set-up a) the leachate collection devices (LCDs) constructed from 10L plastic buckets intercepted all leachate draining through the 2l containers of *Viburnum tinus* 'French White' and b) The lay out of the Mypex plot, plants were blocked in randomised groups of nine.

The volume and N, P and K concentration of the leachate collected in the LCDs was measured periodically over the course of the 20 week experiment (7, 14, 28, 42, 57, 70, 98 and 138 days after potting). At the end of the experiment plant quality was assessed by carrying out a qualitative visual assessment in conjunction with determining dry shoot biomass. The amount of N remaining in the pots was also measured, and the amount of N removed over the course of the experiment was calculated (N content at the start – N content at the end = N removed). This removed N was assumed to be the amount of N which had become plant available over the course of the experiment and was termed 'potentially plant available N'. The proportion of this potentially plant available N which was recovered in the leachate was then calculated to give an estimated N efficiency measure for each growing medium type.

Growing medium type had a highly significant impact on the amount of N, P and K leached from the containers into the environment over the course of the experiment, with as much as 5 x more nutrient being lost from some growing media compared with others. Those media which were made up of components with inherent nutrient content, such as coir (K) and green waste compost (K and P) tended to leach more of these nutrients to the environment. While the absolute amounts of nutrient leached varied widely between medium types the pattern of nutrient loss was similar across all. This was characterised by a large flush of nutrient leaching in the first 7-14 days after potting which accounted for 50-80% of all nutrient lost over the entire duration of the experiment. This magnitude of nutrient loss over such a short-time period is likely to have exceeded legislative acceptable water quality thresholds for N and P concentrations.

There were also differences between growing media types in terms of N efficiency which were not necessarily reflected in the absolute amounts of N lost to the environment. Mixes lost between 32 and 92% of their potentially plant available N to the environment through leaching. There was also a negative relationship between shoot dry biomass and the proportion of potentially plant available N leached to the environment indicating that this N loss through leaching was likely limiting plant growth in some growing medium types.

Temperatures inside containers were often high over the course of the experiment, routinely above 30°C and peaking at more than 45°C. The release patterns of many CRF brands tend to be determined at lower temperatures, routinely 20-21°C. This might suggest that the longevity of many of the products currently incorporated into HONS growing media are being overestimated.

In summary, the work shows that nutrient release patterns in current HONS production systems are poorly matched to plant demand, with a large release of nutrient very early on in the production cycle which is largely lost to the environment. The shift from peat-based to blended growing media is likely to have an important influence on the absolute amounts of nutrient lost in this first flush which needs to be investigated from an environmental pollution perspective. In terms of N efficiency, growing medium type was also important, with potentially large increases in efficiency for some growing medium blends, particularly those containing green waste compost. The data would indicate a potential opportunity to utilise a small proportion (20%) of a nutrient rich organic material in growing medium blends to boost plant N use efficiency and reduce fertilizer application rates. However, more work is required to determine how best to quantify and account for inherent N availability in growing medium components.

Financial Benefits

- The work presented here represents a preliminary study into the impacts of different growing medium blends on nutrient loss and nutrient use efficiency. Further work is needed to elucidate the potential monetary cost and benefits of using one growing medium type over another. Areas of particular financial impact include:
- Better quantification of plant available nutrient content in growing medium component materials (like green waste compost and coir) could facilitate a reduction in fertilizer application rates and improve nutrient use efficiency over the course of the production cycle. More research is needed to determine the best way to achieve this.
- Changes to CRF application strategies, to ensure release patterns better match plant demand could result in reduced nutrient leaching, better plant uptake efficiencies and a reduction in the amount of CRF required per unit volume of growing medium. Further work is required with different CRF release patterns and application approaches to determine best practice.

Action Points

- As the majority of nutrients in this first flush appear to come from the growing medium (rather than the CRF), manufacturers might consider the application of slower-release fertilizers in place of an immediately soluble base fertilizer. This is particularly important in blends of material which include components with inherent nutrient content (such as green waste compost or coir).
- Given that high temperatures and intense periods of rainfall can cause the CRF to release nutrient in excess of plant demand, nutrient-use efficiency might be improved if CRF application was split across the production cycle. For instance, half the CRF dibble applied at potting to promote early plant growth, with the second half top-dressed onto containers 3-4 months later to sustain established plant growth and increase shelf-life.
- Summer temperatures inside the centre of the container were routinely above 30°C. Combining different CRF brands, to include those which release at lower temperatures earlier on in the growing season, with those designed to withstand high temperatures later on, might lead to a better match between fertilizer release patterns and plant demand.

- Given the large amounts of nutrients lost to the environment via leaching, the capture and re-use of water running off nursery beds would seem to be the best long-term solution for improving efficiency and reducing the environmental impact of HONS production.

SCIENCE SECTION

Project 2016-2017: The Impact of different growing medium blends on nutrient loss from container grown hardy ornamental nursery stock (HONS)

Introduction

Optimising nutrition in container grown nursery stock plants is challenging; roots are confined to small volumes and storage capacities for nutrients and water is limited. In the UK, the majority of HNS production occurs outside. Nursery beds are typically irrigated from above using sprinklers; any water which misses the containers or leachate drained through them runs to waste. These open systems necessitate the use of polymer coated controlled release fertilizer (CRF) granules. This is because the coated nature of the fertilizer means nutrient release is restricted, occurring gradually over a period of months to years. In principal only a small amount of nutrient can be lost from containers, regardless of how much rainfall occurs. However, because most potting substrates are relatively chemically inert and experience frequent irrigation and intense rainfall, they are still subject to enhanced nutrient loss via leaching (Oertli, 1980). As a result nutrients tend to be supplied in excess of plant demand and HONS production systems generally have very low uptake efficiencies (Ristvey *et al*., 2007). Adlam *et al*., (2009) investigated the amount of nitrogen and phosphorus being discharged from UK nurseries and found that whilst nitrogen levels were below the thresholds set by the EU water framework directive (EC, 2006), phosphorus levels were often in excess of permitted limits. Previous industry led work examining nutrient loss from CRF fertilized nursery stock in Ireland suggests nutrient losses from peat-based media may be significant, but dependant on rainfall patterns, the plant species grown and CRF application rates (Maher *et al*., 2002). However, peat-use in professional growing medium manufacture has reduced both in absolute and proportional terms over the last 5 years (Denny *et al*., 2016). At the same time, the use of wood-based materials and coir have increased. This trend highlights the shift from almost entirely peat-based substrates to blends or mixtures of a more diverse range of component materials. As reviewed comprehensively by Barrett *et al*., (2016) and highlighted by work carried out previously (Barrett *et al*., 2014; Mulholland *et al*., 2015), growing media based on blends of several material components have physical and chemical properties distinct from traditional peat-based options. This means the way blended substrates retain water and nutrients can vary impacting on nutrient use efficiencies. To date few studies have examined the impacts of different growing medium types on nutrient loss via leaching from HONS production. Those which have been conducted suggest that growing media is likely to have an important impact on the amount of fertilizer lost via container leaching (Chavez *et al*., 2008) both through differences in physical (Niemiera *et al*., 1994) and chemical (Merhaut and Newman, 2005) properties. Indeed, some of the materials in use such as green waste compost, have relatively high intrinsic fertility, so it's important to understand how fertilizer regimes may need to be altered accordingly and how these materials are impacting on leachate nutrient concentrations. As blended peat-free and peat-reduced growing media are increasingly taken up by UK growers, it is important to understand what impact changes in substrate composition might be having on the efficiency and environmental impact of the production process as a whole. The work described below seeks to start bridging this knowledge gap.

There were four main aims:

1. To quantify the amount of nitrogen, phosphorus and potassium leaching from 6 different growing medium types under simulated HONS nursery conditions.
2. To determine whether nutrient leaching differed in terms of magnitude and pattern of release between growing medium types.
3. Investigate the relative efficiencies of N use (N available for plant uptake vs N lost via leaching) in a range of blended growing media.
4. To investigate the extent to which CRF contributed to leachate nutrient content, and whether there was any evidence to suggest CRF function was influenced by growing medium composition

The results will help inform growers on how nutrient management practices may need to be amended when switching from a peat-based to blended growing medium.

Materials and methods

Growing medium treatments

The six growing medium types comprised of 5 peat-free or peat-reduced blends of component materials and one peat-based industry standard mix (InS). All media had been previously trialled (Barrett *et al*., 2014) and shown to produce marketable quality plants (Appendix 3, Table B). Growing medium material components were selected according to common-use in the UK. These were professional standard Irish sphagnum peat graded to 18mm. Coir from Sri Lanka, washed and buffered. Mature (aged) potting grade pine bark. Wood fibre, comprised of machine extruded pine chips compensated with additional nitrogen. All materials were supplied in 80l bags and used within 2 weeks of receipt. The garden waste compost (GWC), was produced on site at RHS garden Wisley (Surrey, UK). It was comprised of clean garden trimmings, which were windrowed and turned; within pile temperatures were monitored until the resultant material was considered stable. The mature compost was then screened to 20mm before being incorporated into the growing medium blends. For each material component, physical and chemical properties were characterised using British/European standard methods carried out either by an accredited commercial laboratory or in-house at RHS garden Wisley (Appendix 4, Table C), results are provided in Appendix 5 (Tables D and E).

The 6 growing medium types were manufactured on site at RHS garden Wisley (June 2016), using different proportions (by volume) of the 5 raw materials as displayed in Figure 1.

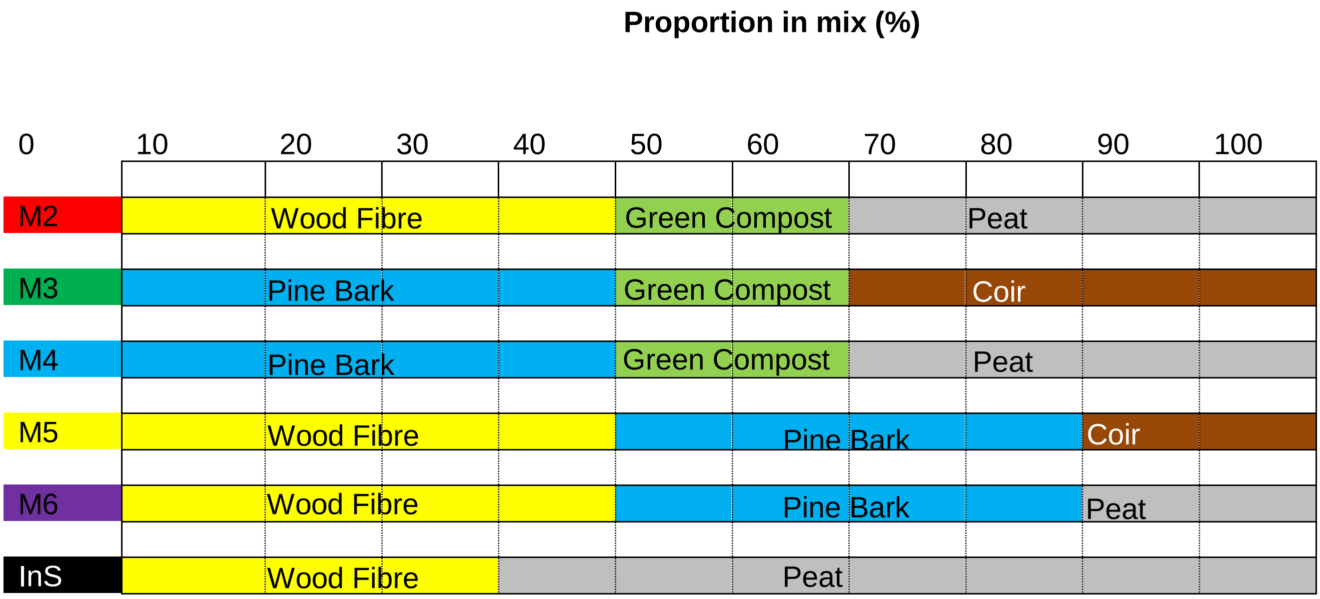

Figure 1. Material composition of the 5 blended growing medium types and the industry standard mix (InS). Growing medium mixes are based on different proportions of coir (brown), GWC (green), peat (grey), pine bark (blue) and wood fibre (yellow).

Growing media were made up uniformly in 45l (90l for mixes 5 and InS) batches using a clean cement mixer. All growing media were amended with the same rate of water soluble base fertilizer (15N-10P-20K), fritted trace elements (vitreous enamel powder containing plant micronutrients) and wetting agent. Horticultural lime was applied where required to the peat-containing mixes to bring the pH into an acceptable range for plant growth. Supplemental calcium ammonium nitrate (CAN) was also added to compensate for microbial uptake of nitrogen in the woody growing media components (Scott, 1986), amounting to 100g/m^3 of CAN for every 10% of woody materials making up a mix (up to a maximum of 500g). The growing media were transferred to porous bags and used within 1 week. Once manufactured, representative samples of each growing medium type were taken for physical and chemical characterisation as above.

Leachate capture devices

Leachate capture devices (LCDs) were constructed (Image 2), from a design adapted from Birrenkott *et al*., (2005). Units were assembled by placing a standard 2l black nursery container through a hole cut into the lid of a 10.4l black plastic (polypropylene) bucket (Ampulla, Cheshire. UK). The container was then fixed into the lid using a water activated polyuretene adhesive (Gorilla glue brand, www.screwfix.com) which expanded as it dried to form a water tight seal between the lid and the sides of the pot. This ensured only water passing through the container was intercepted. The container was positioned into the lid so that the bottom 2.5 cm of it protruded through into the centre of the bucket (Image 2) and the drainage holes were clear of the lid.

Image 2. Leachate capture devices (LCD) were constructed to capture all leachate drained from the experimental containers so that the volume and nutrient content could be quantified

Plant material

The cultivar *Viburnum tinus* ‘French White’ was selected as it is widely grown by commercial HONS producers. Plants were purchased as 9cm liners in May 2016, and were monitored for 4 weeks for any sign of pest and disease prior to the start of the experiment.

Planting and cultural methods

The experiment was conducted at the field research facility at RHS garden Wisley (Woking, Surrey, UK) for 25 weeks between 7th June and 24th October 2016. For each growing medium type, 9 replicate liners were potted up into the 2l pots which had previously been adhered to the lids of the LCD. Pots were half filed with growing media, and 8g of CRF was dibbled into the pot before placement of the liner plant and infilling. Two additional treatments were also included; for mixes 5 and InS, 9 replicates were potted up exactly as above but without the addition of any CRF.

The CRF was a phenolic resin and polymer coated 12 month product, comprised of 2-4mm sized granules and containing 18% N, 6% P and 12% K (Plantacote®, Top N, 12M; Aglukon, Duesseldorf, Germany). The manufacturer’s information stated that nutrient release was temperature dependant and unaffected by substrate type, pH or moisture content. The specified 12 month longevity of the product was determined at a temperature of 21°C, a reduction in longevity to 10 months was predicted at temperatures of 27°C. The mode of action was described as: ‘water absorption through the coating which dissolved the nutrient salts inside. The dissolved nutrients pass outwards through the coating due to osmotic pressure’. Nutrient release was predicted to begin 2-3 weeks after incorporation, although this lag in release would presumably be dependent on the temperature.

All 72 plants were then placed atop LCDs and moved onto the trial area which comprised of an 8 x 12m Mypex membrane covered area. Replicates were arranged in 9 randomised blocks, with each block containing 1 randomly assigned replicate from each of the 8 treatments. In addition, within each block an additional leachate collection device was included which contained an empty 2l pot (Image 3).

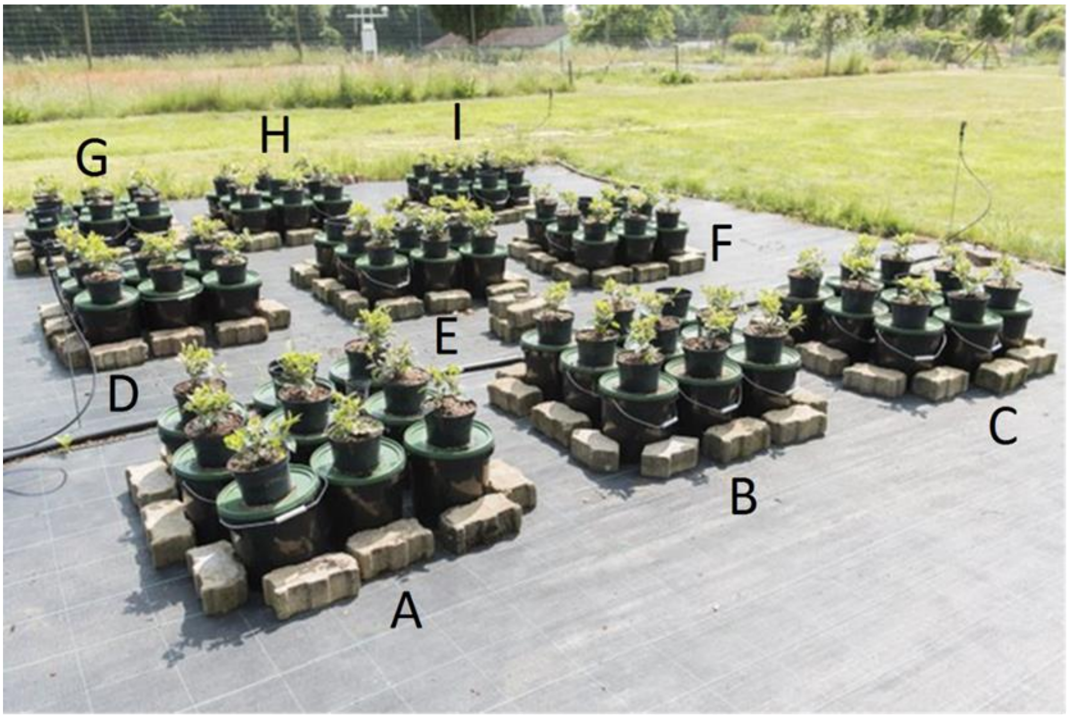

Image 3. Lay-out of the experimental plot, with replicate LCDs randomly assigned to each of the 9 blocks. Each block contained 8 planted LCDs and 1 unplanted.

Plants received rainfall which was supplemented with overhead sprinklers laid out to optimise efficiency (AHDB Horticulture, 2005: Factsheet 16/05). Supplementary overhead irrigation was controlled by manual monitoring of growing media moisture levels using a moisture probe (SM200 moisture sensor, Delta-T devices, Cambridge, UK). Measurements were taken daily from all replicates containing mixes 5 and InS as they had the least and most water-holding capacity respectively. Laboratory experiments had been conducted previously to determine wilting point in each of these growing media and relate these plant responses to readings on the moisture probe (Barrett, 2014, unreported). These data were used to create trigger-points for each medium type with regard to when and for how long irrigation was applied. Ten rain gauges were placed uniformly across the plot, these were read and emptied every 24 hours to establish a record of on-plot water reception. In addition a rain gauge was placed adjacent to the plot, outside the range of the irrigation system so the frequency of rainfall events could be recorded over the duration of the experiment. Large weeds were removed from pots monthly, and pest and disease inspections were carried out weekly. Two spray treatments for aphids were carried out (0.05g/l acetamiprid) on the 15th July and the 8th September.

Leachate collection and leachate analyses

Previous studies examining nutrient loss from container grown HNS using polymer coated CRF under field conditions indicate that most leaching occurs within the first 9 weeks after potting (Cox, 1993; Huett, 1997; Merhaut *et al*., 2006) and then tails off after 15-20 weeks (Mikkelsen *et al*., 1994; Merhaut *et al*., 2006). As a result the first leachate sample was taken 7 days after potting with further sampling at 14, 28, 42, 57, 70, 98 and 138 days. Sampling at 70 days indicated very little nutrient was leaching from containers, so sampling intervals were lengthened.

Leachate sampling commenced at least one hour after the last rainfall/irrigation event, for each of the 72 planted and 9 empty LCDs. The lid of each LCD was removed and the volume of leachate collected was measured and recorded. A 50ml sample of the leachate was then taken and the remaining leachate discarded. Leachate samples were sent immediately to an accredited commercial laboratory for determination of N K and P concentration (NRM Laboratories, Bracknell, UK). The water collected from the 9 unplanted LCDs were used to determine background levels of nutrient in the irrigation water. Total N, P and K leached from each replicate was calculated for each collection interval by multiplying nutrient concentration x leachate volume and subtracting the amount of nutrient recorded in the unplanted LCD. Cumulative nutrient leached for each treatment was calculated by summing total nutrient recovered at each preceding sampling interval (e.g. total N leached at 138 days was the sum of N lost at 7+14+28…and so forth). Total N, P and K was divided by the number of days since the last sampling interval to obtain daily leach rate.

Container temperatures

As CRF nutrient release is temperature dependant, growing medium temperature inside the containers was monitored over the course of the experiment using ibutton DS1922L Thermochron data loggers (Measurement Systems Ltd, Newbury, UK), which stored a temperature reading once per hour. These were enclosed in waterproof capsules and placed in the centre of pots at the start of the experiment (directly under the CRF and *Viburnum* liner). Loggers were placed in all replicates making up 4 of the 9 blocks of plants (A,G,E and I) so that each treatment had 4 temperature records spaced across the entire experimental plot (32 loggers in total).

Plant quality assessment

At the end of the experiment, plants were assessed visually for quality by a group of professional and amateur growers (33 assessors, 11-20th October 2016). Each assessor scored all the experimental plants on a scale of 1-5 according to their visual suitability for sale to (professionals) or purchase from (amateurs) a garden centre retailer; 1 being extremely poor quality, 5 being highest quality and a score above 3 indicating saleable/purchase worthy plants. Example plants for each quality category were displayed to guide the assessors with leaf colour and canopy thickness being the key quality indicators. After visual assessment all planted LDCs were harvested oven dried (60°C for 48 hours) and weighed to determine shoot dry biomass per container.

Growing medium nitrogen efficiency

After the plants were harvested, the growing media from all 8 treatments were analysed for remaining nitrogen, phosphorus and potassium content. For treatments with CRF, 5 replicate containers of each growing medium type had all the CRF granules carefully removed by hand. As much root material as possible was also removed and samples were analysed for total N, P and K as described above. The remaining 4 replicate containers of each growing medium type were analysed in the same way but the CRF prills were mixed in evenly and then the medium and CRF were milled to give a total N, P and K content for the growing medium + CRF. The amount of nutrient remaining in the CRF could then be estimated by subtracting the nutrient content of the growing medium from the nutrient content of the growing medium + CRF.

Because of the variable nutrient content of the component materials, the 6 growing medium types all started the experiment with different N, P and K contents. Therefore, in order to better understand nutrient use efficiency in each of the growing medium types, an estimated nitrogen balance was constructed for each (nitrogen being the most mobile and abundant nutrient). The starting and ending nitrogen content of a 2l container of each medium type was used to calculate the amount of nitrogen which had been 'removed' over the course of the experiment. This 'removed N' pool accounted for what had been either taken up by the plant, or lost to the environment (either as gaseous emission or leachate). In this way it provided an estimate of the amount of total N which had become potentially plant available (PPAN) over the course of the experiment. As the amount of nitrogen leached from each treatment was quantified, an estimate of the proportion of this 'potentially plant available nitrogen' which had been leached could be calculated.

- N (g) in container at start - N (g) at end = PPAN
- N (g) leached/PPAN (g) x 100 = % PPAN leached

Data analysis

Leachate volumes, total N, P, K leached per container/pot and the plant quality variables (shoot dry biomass and visual quality score) were analysed with one-way analysis of variance (ANOVA) using growing medium type as the main effect (accounting for block effect). For the in-pot temperature data, daily and weekly average temperatures were calculated per pot and analysed with two-way ANOVA using growing medium type and block position as the two main effects. Cumulative N, P and K leaching rates per pot were analysed with two-way ANOVA, using the main effects of growing medium type and time. For mixes 5 and InS with and without CRF, N, P and K leaching rates per pot per day were analysed for the period 7-14 days after potting using two-way ANOVA, and the main effects of growing medium type and CRF incorporation. In all ANOVA analyses, where the main effects, or interaction term were significant differences between means were compared with an LSD post hoc test. The relationship between plant dry biomass and the proportion of potentially plant available N leached was analysed with linear regression. All data were transformed as required, data are displayed as means ± 1 standard deviation and all statistical analysis was carried out using GenStat, edition 10. One of the plants grown in mix 2, appeared to stop growing a month into the experiment, it was presumed that this was due to root disease and this replicate was excluded from all data analysis.

Results

Growing medium properties

Physical and chemical characterisation of the 6 growing medium types showed that each had a distinct physiochemical character (particle size distribution, AFP, WHC, organic matter content, bulk density and chemical properties are displayed in Appendix 6, Table F and G). As displayed in Figure 2, there was a significant difference ($p<0.001$) in the water holding capacity of the media at increasing suction (representing increasing plant water demand). Mixes 5 and 6 were the most freely draining mixes, containing the lowest % water at all suctions (Figure 2). Mixes 3 and 4 held more water at all suctions than mixes 5 and 6, indicating a consistently higher water holding capacity. Despite being composed of very different material combinations, InS and mix 2 had a relatively similar pattern of water holding capacity, tending to hold most water of all the media at lower suctions (0-2kPa). However, at higher suctions, mix 2 held less water than mixes 3, 4 and InS, suggesting that its ability to retain water reduced more quickly as plant demand increased, than in these other mixes.

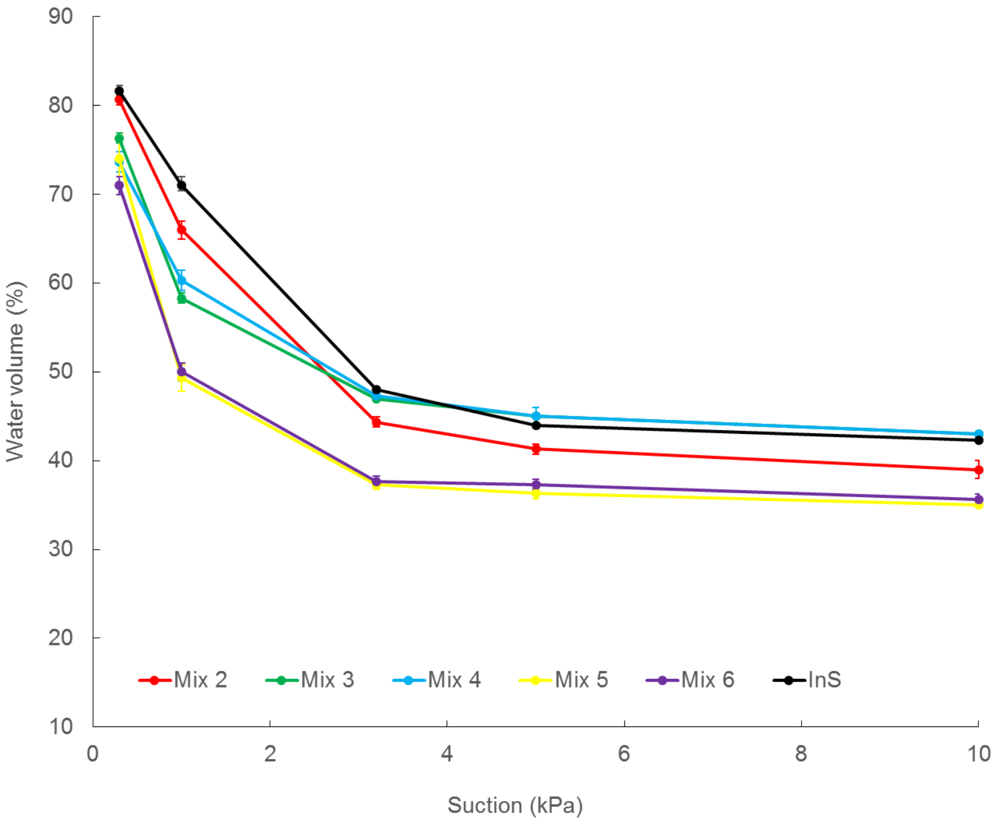

Figure 2. Water volume (%) of the 6 growing medium types at increasing suction (kPa). Data are means ± one standard deviation (n=3)

In terms of relative nutrient content between mixes, Table 1 gives an overview of the total (plant available and unavailable) N (1a), P (1b) and K (1c) content of a 2l replicate pot of each growing media type at the beginning of the experiment. Nutrient content varied quite widely between treatments particularly for N with 3.85g for mix 5-CRF but 11.73g in mix 2.

Table 1. Total N (g), P (g) and K (g) content for a 2l pot of each of the 8 experimental treatments (6 growing medium types, with Mix 5 and mix InS included both with and without a CRF). Total nutrient content per pot is broken down by the contribution from the controlled release fertilizer (CRF), growing medium additives (additives) and the component materials themselves (materials). Total N was determined using BS EN 13654-2:2001, total P and K were determined using BS EN 13650:2001 (See Appendix 4, table C).

a)

Growing media	CRF N	Additives N	Materials N	Total N per pot
	g	g	g	g
Mix 2	1.44	0.71	9.58	11.73
Mix 3	1.44	0.71	7.07	9.22
Mix 4	1.44	0.71	9.08	11.23
Mix 5	1.44	0.71	3.14	5.29
Mix 6	1.44	0.71	4.60	6.75
InS	1.44	0.44	9.57	11.45
Mix 5 - CRF	0	0.71	3.14	3.85
InS - CRF	0	0.44	9.57	10.01

b)

Growing media	CRF P	Additives P	Materials P	Total P per pot
	g	g	g	g
Mix 2	0.48	0.2	1.21	1.89
Mix 3	0.48	0.2	1.18	1.86
Mix 4	0.48	0.2	0.82	1.50
Mix 5	0.48	0.2	0.27	0.95
Mix 6	0.48	0.2	0.21	0.89
InS	0.48	0.2	0.27	0.95
Mix 5 - CRF	0	0.2	0.27	0.47
InS - CRF	0	0.2	0.27	0.47

c)

Growing media	CRF K	Additives K	Materials K	Total K per pot
	g	g	g	g
Mix 2	0.96	0.4	3.75	5.11
Mix 3	0.96	0.4	5.59	6.95
Mix 4	0.96	0.4	3.13	4.49
Mix 5	0.96	0.4	2.04	3.40
Mix 6	0.96	0.4	1.12	2.48
InS	0.96	0.4	0.74	2.10
Mix 5 - CRF	0	0.4	2.04	2.44
InS - CRF	0	0.4	0.74	1.14

As all mixes received a similar amount of nutrients from the CRF and growing medium additives, these large differences were attributable to the nutrient content of the different component materials (Table 2). These contained very variable nutrient levels; the coir and GWC being relatively high in K and the GWC containing 5x as much P as any of the other materials. The peat contained a relatively high content of N, particularly when compared with the wood fibre, pine bark and coir. However, the extent to which these nutrients would become available for plant uptake over the course of the experiment was unknown.

Table 2. Total N, P and K content (g) of the growing medium component materials ($g{\cdot}kg^{-1}$). Data were obtained by analysis of three representative samples of each material type. Total N was determined using BS EN 13654-2:2001, total P and K were determined using BS EN 13650:2001 (See Appendix 4, table C).

Growing medium Component	Total N	Total P	Total K
	$g{\cdot}kg^{-1}$	$g{\cdot}kg^{-1}$	$g{\cdot}kg^{-1}$
Coir	4.80	0.38	7.33
GWC	8.73	1.90	6.68
Peat	13.13	0.15	0.05
Pine Bark	4.10	0.26	1.66
Wood fibre	2.47	0.07	0.37

Temperature and rainfall patterns over the course of the experiment

Temperatures recorded inside the pots (in pot) were similar across the experimental plot but varied between mixes (p=0.030). However, the difference between the average weekly temperature in the warmest (mix 6) and coolest mix (mix 3) was 1°C which was unlikely to be of horticultural significance. Figure 3 shows the average weekly temperature in the pots over the course of the experiment which ranged from 7.6 to 30°C. The highest hourly temperature recorded inside the pots was for mix 6, which reached 46.1°C. Weekly rainfall volumes over the course of the experiment are also displayed; there were some notably intense rainfall events over the course of the experiment which are reflected in the weekly totals. During the third week of the experiment (day 16 after potting) 42.4mm of rain fell in less than 8 hours. Eight weeks into the experiment (day 56 after potting) 14.6mm fell in around 6 hours and 15 weeks into the experiment (day 101), 25.8mm fell in under 10 hours.

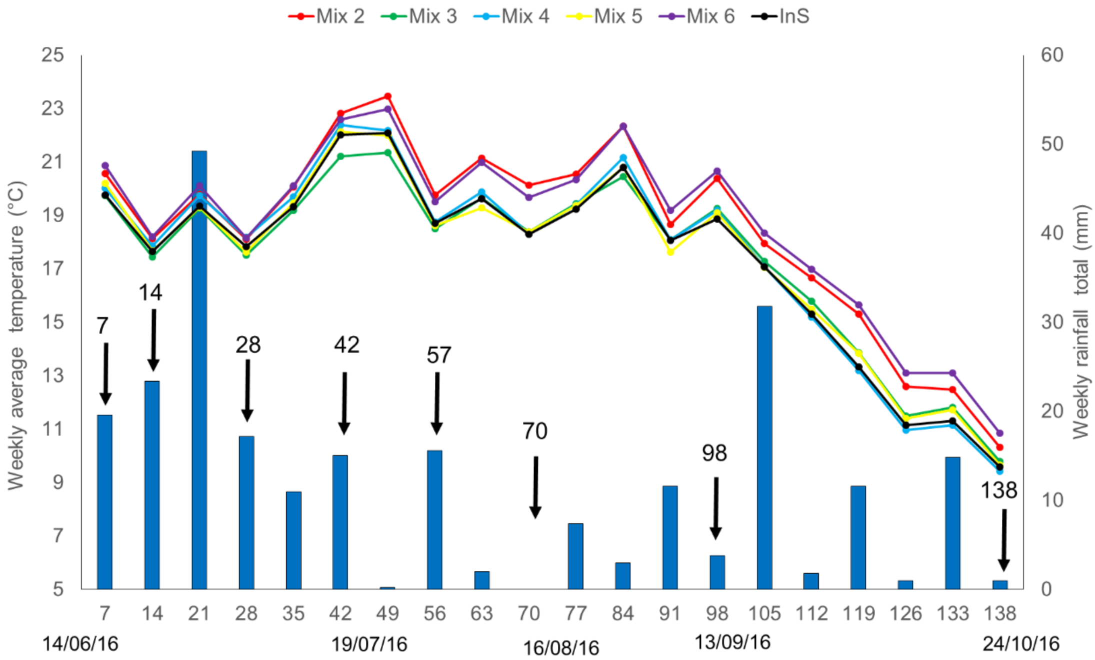

Figure 3. Mean weekly in pot temperatures (°C) for each of the 6 growing medium types (primary axis) and on plot weekly rainfall totals (mm, secondary axis) for the duration of the experiment. Daily temperatures are the mean of readings taken every hour for 24 hours by the in pot loggers. Rainfall data reflects the total amount collected in the on plot rain gauges over the same 24 hour period. Leachate sampling points are indicated with black arrows, occurring at 7 (14/06/2016), 14, 28, 42, 57, 70, 98 and 138 (24/10/2016) days after potting.

Cumulative nutrients losses from different growing media

Across all six growing medium types and for all three nutrients the pattern of nutrient loss was characterised by a large amount of nutrient leaching in the first 14 days after potting which accounted for a high proportion (70-81% of N leached, 53-86% of P leached, 58-65% of K leached) of the total leached over the whole experiment. After this early flush, nutrient leaching tended to reduce substantially towards a plateau.

The mean cumulative nitrogen leached per pot is displayed in Figure 4, and was strongly influenced by both growing medium type and time ($p<0.001$, in both cases). A significant interaction (p<0.001) also indicated that the effect of growing medium on N leaching varied over the course of the experiment. At the first sampling point, 7 days after potting, N leaching was highly variable and did not differ between mixes (20.9 ± 57mg). Between 7 and 14 days, there was a very large increase or flush in N leaching from all 6 mixes. N lost over this period was two orders of magnitude higher than at any other time during the experiment. During this early flush, mixes 5 and 6 leached significantly less N than mixes 2, 3 and 4, with the InS losing less than all other media. Between 28 and 42 days after potting, the N which had been leached from all media was similar with the exception of mix InS which had leached significantly less than all other medium types. As the experiment progressed from 57 to 138 days after potting, cumulative N loss was consistently higher in mixes 3 and 4 than mix 2. Over this same period, mix 6 leached a similar amount of N to both mixes 3, 4 and 2. In contrast, mix 5 had leached less N than any of the other mixes except mix InS which leached consistently less N than all other growing medium types.

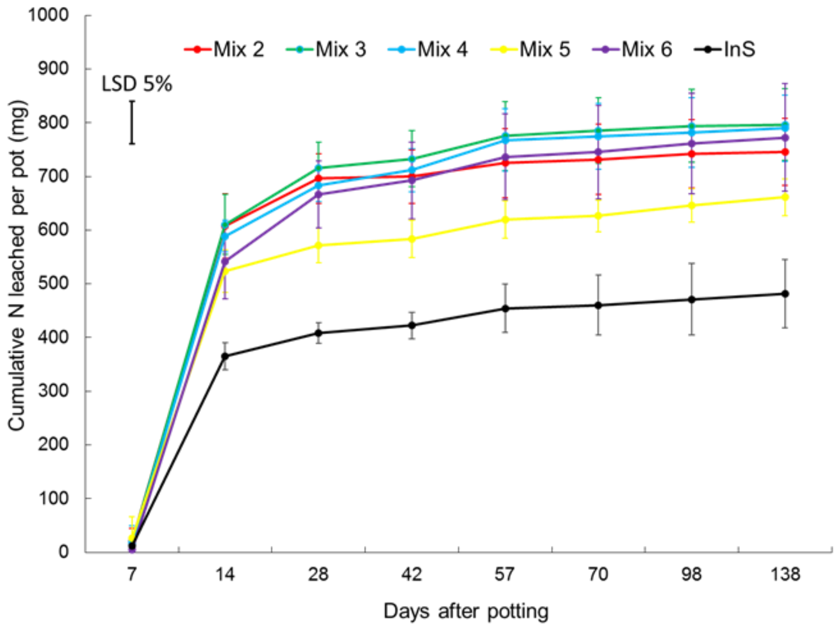

Figure 4. Cumulative leaching (mg) per pot of nitrogen (N), from the 6 growing medium types at 7, 14, 28, 42, 57, 70, 98 and 138 days after potting. Data points displayed are the mean of 9 replicates (with the exception of mix 2, which had eight replicates at 7, 14 and 28 days and seven at 42, 57, 70, 98 & 138d and mix 5 which had eight replicates at 138d) ± 1 standard deviation. The LSD between treatments-by-medium combinations (5% level) is displayed.

Cumulative P leached per pot through time is displayed in Figure 5 and was again strongly influenced by growing medium type and time (*p*<0.001, in both cases). A significant interaction (*p*<0.001) also indicated that the effect of growing medium on P leaching varied through time. Amounts of P leached in the first 7 days after potting were highly variable and did not differ between mixes (2.41 ± 3.61mg). As with N, a large increase or flush in P leaching was present at between 7 and 14 days after potting. P leached over this time period was one order of magnitude higher than at any other point over 20 week experiment. During this 7 day leaching flush, mix 4 lost more P than all other media types, followed by mix 3. Mixes 2, 5, 6 and InS had all leached similar amounts but less than mixes 3 and 4. After this initial flush of P leaching, mixes 3 and 4 continued to leach P to the environment in higher amounts than any of the other medium types. In contrast, P leaching in mixes 2, 6, 5 and InS tended to plateau with little change in the absolute amounts lost between 28 and 138 days after potting. Notably, cumulative P leaching plateaued very soon after potting in mixes 5 and InS, with virtually no additional P leached 28 days after potting.

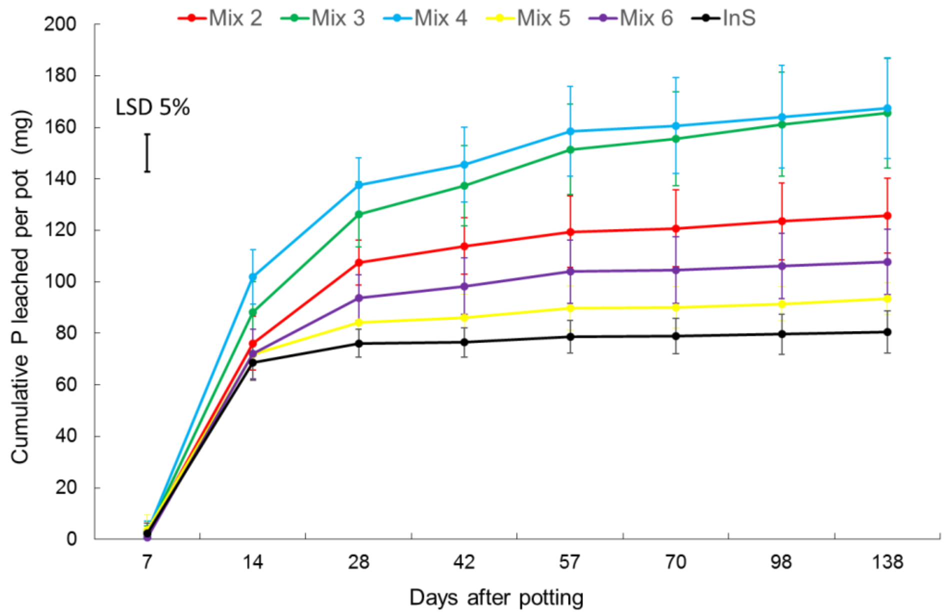

Figure 5. Cumulative leaching per pot (mg) of phosphorus (P), from the 6 growing medium types at 7, 14, 28, 42, 57, 70, 98 and 138 days after potting. Data points displayed are the mean of 9 replicates (with the exception of mix 2, which had eight replicates at 7, 14 and 28 days and seven at 42, 57, 70, 98 & 138d and mix 5 which had eight replicates at 138d) ± 1 standard deviation. The LSD between treatments-by-media combinations (5% level) is displayed.

As with the other nutrients there was a distinct flush of K leaching early on in the experiment at between 7 and 14 days after potting (Figure 6). The rate of K leached over this time period was 3-4x higher than at any other point in the experiment. The amount of cumulative K leached through time was strongly dependant on growing medium type (p<0.001), with mixes showing a consistent pattern of leaching losses throughout the 20 week experiment. Pots containing mix 3 leached substantially more K than any of the other medium types at every sample point. Mixes 2 and 4 leached K in a very similar way, losing less than mix 3 but more than mixes 5, 6 and InS at every sample point. Mix 5 leached more K to the environment than mix 6 early on in the experiment, but by 42 days after potting both mixes were leaching a similar amount; which was consistently more than mix InS but less than the other media types. Mix InS always had a lower rate of K leaching than any of the other growing medium types, with K losses plateauing after the initial 7-14 day leaching flush.

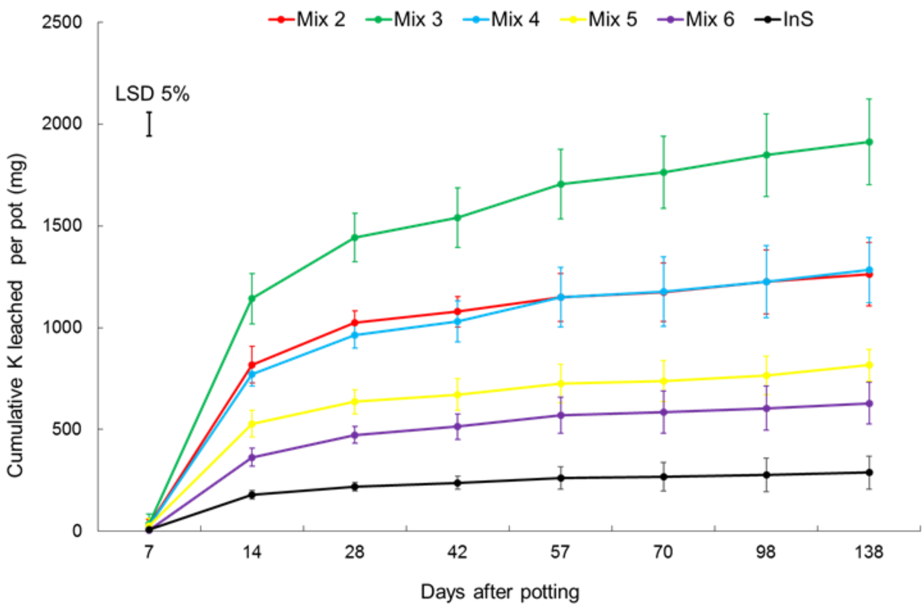

Figure 6. Cumulative leaching (mg) of a) nitrogen (N), b) phosphorus (P) and c) potassium (K) per pot for the 6 growing medium types at 7, 14, 28, 42, 57, 70, 98 and 138 days after potting. Data points displayed are the mean of 9 replicates (with the exception of mix 2, which had eight replicates at 7, 14 and 28 days and seven at 42, 57, 70, 98 & 138d and mix 5 which had eight replicates at 138d) ± 1 standard deviation.

In terms of the total amount of the 3 nutrients leached per pot from all medium types over the course of the 20 week experiment, the data are summarised in Table 3. Growing medium type had a highly significant impact on total nutrient leached to the environment (Table 3, $p<0.001$ for all 3 nutrients). With regard to N, by the end of the experiment, pots containing mixes 3, 4 and 6 had leached a similar amount of N to the environment. Mix 2 lost significantly less than mixes 3 and 4, but a similar amount to mix 6. Pots containing mix 5 had leached between 135-111mg less N to the environment than those containing mixes 2, 3, 4 and 6. Mix InS leached between 30-40% less than any of the other media. For phosphorus, mixes 3 and 4 leached more than any of the other media, followed by mix 2>mix 6>mix 5. Mix InS lost between 14-52% less P to the environment than any other medium type. The absolute amounts of K leached to the environment per pot were greater than for the other two nutrients, with the biggest differences in leaching between mixes. Mix 3 leached the most K of all the medium types, followed by mixes 2 and 4 which lost a similar amount. Again, mix InS leached the least K; around 3x less than mix 5, and about 6x less than mix 3.

Despite these clear differences in the amounts of nutrient leached between growing media and despite their clearly distinct water holding capacities (Figure 2), the total volume of leachate collected per pot did not vary between them (p= 0.314, Table 3). Volumes of leachate collected both within and between treatments were highly variable ranging from 15.9 ± 5.4 L for the InS mix to 19.5 ± 2.6 L for mix 3.

Table 3. Mean volume of leachate (L) and N (mg) lost per pot to the environment by the end of the experiment for the 6 growing medium types. Mix composition is given as % volume of each raw material component (GWC; garden waste compost, C; coir, P; peat, PB; pine bark and WF; wood fibre). Data are displayed as means ± 1 standard deviation, n = 9 (with the exception of Mix 2 where n=7 and Mix 5 where n=8). Significant differences between values are denoted with letters and determined by a least significant difference (LSD) post hoc test.

Growing medium	Leachate volume	N Leached	P Leached	K leached
	(L)	(mg per pot)	(mg per pot)	(mg per pot)
Mix 2	18.4 ± 6.8	745.4 ± 62.2[a]	125.6 ± 14.5[b]	1261.9 ± 155.2[b]
Mix 3	19.5 ± 2.6	796.6 ± 66.8[a]	165.5 ± 21.3[a]	1913.2 ± 211.5[a]
Mix 4	16.4 ± 3.1	789.8 ± 61.8[a]	167.5 ± 19.5[a]	1282.9 ± 160.4[b]
Mix 5	17.5 ± 3.6	661.0 ± 34.0[b]	93.6 ± 6.2[d]	816.4 ± 78.4[c]
Mix 6	17.1 ± 5.3	772.4 ± 100.4[a]	107.8 ± 12.7[c]	629.3 ± 103.5[d]
InS	15.9 ± 5.4	481.7 ± 63.6[c]	80.4 ± 8.2[e]	288.3 ± 81.1[e]

The contribution of the CRF to leached nutrients

The total amount of nutrient leached from mixes 5 and InS over the course of the experiment both with and without CRF are summarised in (Table 4). For mix 5, pots containing CRF leached more N than those without CRF (c. 20%; p<0.001). In contrast, there was no difference in the amount of P and K leached from mix 5 when comparing with and without CRF.

For mix InS, pots containing CRF leached more N and P than pots without CRF (c. 26 and 14% respectively; p>0.001), but there was no difference in the amount of K leached.

Table 4. Total N (mg) leached per pot to the environment by the end of the 20 week experiment for mixes 5 and the InS with and without (-CRF) inclusion of CRF. Data are displayed as means ± 1 standard deviation, n=9 (with the exception of mix 5 where n=8). Significant differences between values are denoted with letters and determined by a least significant difference (LSD) post hoc test.

Growing medium	N Leached per pot	P leached per pot	K leached per pot
	(mg)	(mg)	(mg)
Mix 5	661.02 ± 33.95[a]	93.6 ± 6.2[a]	816. 4 ± 78.4[a]
Mix 5-CRF	529.93 ± 60.50[b]	91.3 ± 9.5[a]	763.7 ± 89.2[a]
InS	481.74 ± 63.59[b]	80.4 ± 8.2[b]	288.31 ± 81.1[b]
InS-CRF	357.87 ± 25.80[c]	69.4 ± 3.1[c]	228.4 ± 37.0[b]

Table 5 compares the rate of nutrient loss in the first 7-14 days the experiment between those pots which contained CRF and those which did not. The rate of nutrient loss over this period was strongly influenced by growing medium type for all nutrients (p<0.001), with mix 5 tending to leach more nutrient than mix InS regardless of whether the CRF was included or not. For pots containing mix InS, those with CRF leached N and P at a higher rate than those without, but the differences were small (7mg·d^{-1} N and 1 mg·d^{-1} P). For mix 5 the leaching rate for all three nutrients was similar regardless of whether pots contained CRF. This suggested nutrient loss from the CRF was contributing little to this 7-14 day flush of nutrient leaching.

Table 5. Leaching rate (mg·d^{-1}) per pot of N, P and K from mixes 5 and InS at 7-14 days after potting both with and without (-) CRF included. All data are displayed as means ± 1 standard deviation (n=9, except mix 5 – CRF where n=8). Significant differences between values are denoted with letters and determined by a least significant difference (LSD) post hoc test

	Sampling period: 7-14 days		
Growing medium	**N leaching rate**	**P leaching rate**	**K leaching rate**
	per pot (mg·d^{-1} per pot)	per pot (mg·d^{-1} per pot)	per pot (mg·d^{-1} per pot)
Mix 5	71.0± 8.5[a]	9.7 ± 1.8[a]	71.8 ± 11.5[a]
Mix 5 -CRF	65.2 ±11.2[a]	9.3 ± 1.4[ab]	68.7 ± 10.3[a]
InS	50.4 ± 3.7[b]	9.5 ± 0.9[a]	24.7 ± 2.6[b]
InS-CRF	43.5 ± 5.5[c]	8.5 ± 0.9[b]	21.4 ± 2.9[b]

The impact of growing medium type and CRF exclusion on plant biomass

Growing medium type had a strong influence on shoot dry biomass (Figure 7, p<0.001); where CRF was incorporated there was a *c.* 5g difference between plants with the highest (mix 4) and lowest mean biomass (mix 5). Plants grown in mix 5 produced less biomass than those plants grown in any of the other media with CRF except mix InS. It was also notable that plants grown in that mix 2 produced plants of higher shoot dry biomass than those grown in mix InS. Excluding CRF from both mixes 5 and InS had a clear detrimental impact on shoot dry biomass reducing it by about half in both medium types.

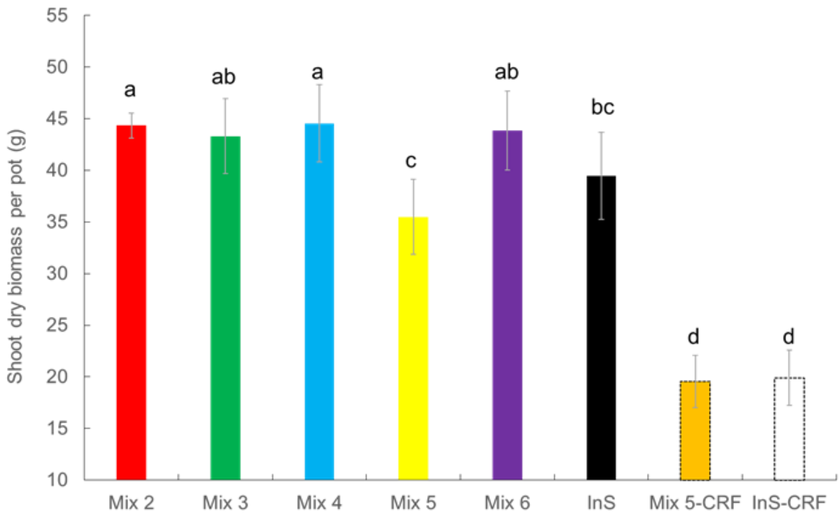

Figure 7. Shoot dry biomass (g) per pot of Viburnum tinus 'French white' grown in the 6 growing medium types with CRF (18-6-12, 4g/l) and in mixes 5 and InS without (-) CRF. Data are means of 9 replicates ± 1 standard deviation (n =9). Significant differences between values are denoted with letters and determined by a least significant difference (LSD) post hoc test.

The impact of growing medium type and CRF exclusion on plant visual quality

Growing medium type had a strong influence on the perceived visual quality of the plants (Figure 8, $p<0.001$). Participants of the quality assessment were clearly able to discern differences in plant size between treatments, thus trends in visual scores tended to follow those identified in the shoot dry biomass data. Plants grown in mixes 2, 3, 4 and 6 were all of similar perceived quality receiving a score of ~ 4. Participants were able to discern a slight decrease in quality for plants grown in mix InS, scoring them lower than those grown in mixes 2 or 4. Mix 5, was perceived to produce visually poorer quality plants than mixes 2, 3 and 4, with a mean score of 3.4. Plants grown in mixes 5 and InS without CRF were deemed to be unmarketable with a mean score of ~2. These plants were visibly stunted, discoloured and clearly suffering from nutrient deficiency (Image 4).

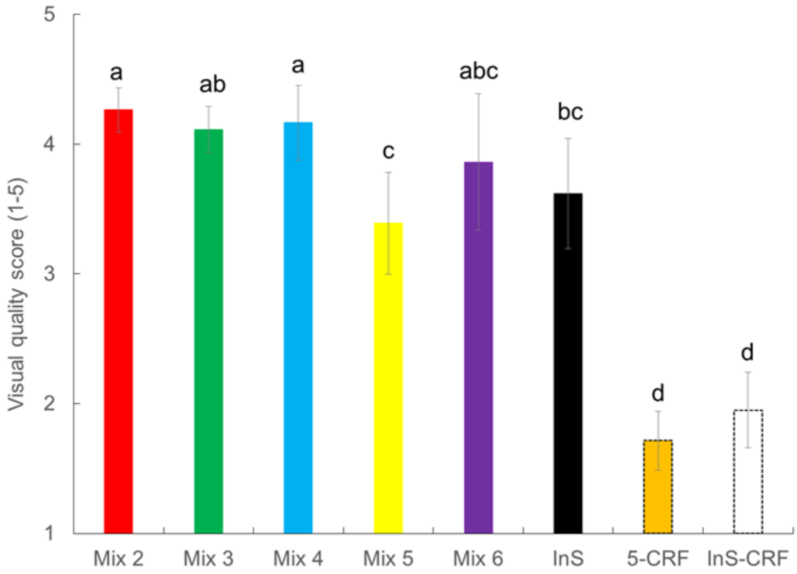

Figure 8. Visual quality score (1-5) for *Viburnum tinus* 'French White' grown in the 6 different growing medium types with CRF (18-6-12, 4g/l) and in mixes 5 and InS without (-) CRF. Data are means of 9 replicates ± 1 standard deviation (n =9 with the exception of mix 2 where n=8). Significant differences between values are denoted with letters and determined by a least significant difference (LSD) post hoc test.

Image 4. Visual quality categories for Viburnum tinus 'French White' grown in the experiment. Plants were scored by a group of professional and amateur growers (33 assessors, 11-20th October 2016). Each assessor scored all the experimental plants on a scale of 1-5 according to their visual suitability for sale (professionals) to or purchase (amateurs) from a garden centre retailer; 1 being extremely poor quality, 5 being highest quality and a score above 3 indicating commercially marketable). Plants grown in mixes 5 and InS without CRF tended to be scored at the lower end of the scale being stunted, discoloured and generally perceived to be unmarketable.

The impact of growing medium type on estimated nitrogen use efficiency

Figure 9 displays a proportional break-down of the fate of N in containers of each growing medium type. The first pie chart on the left of each pair describes the amount of N that was 'removed' or made potentially plant available from each mix over the course of the experiment (total N (g) at the start – total N (g) at the end). Over the experimental period, mixes 2, 3, 4 and 6 lost a roughly similar proportion of their starting N content; (18 and 24%), suggesting that approaching one quarter of their total N content had become potentially plant available. For mix 5, this proportion was lower at 14%. Mix InS, whilst starting with the one of the highest total N contents of all the mixes, had lost just 7% of this by the end of the experiment. This suggested that between 2 and 3 times less of its total N content had had become potentially plant available when compared with the other medium types.

The amount of N leached into the LCDs as proportion of the potentially plant available N 'removed' from the media is shown on the right of each pair of pie charts below. For mixes 4, 3 and 2 the amount of N recovered in the leachate accounted for between 32 and 39% of the potentially plant available N per pot respectively. For mix 6, the proportion of this N recovered in the leachate was higher at 48%, indicating almost half of all the N which had become available over the course of the experiment had been lost to the environment. For mixes 5 and InS, the proportion of potentially plant available N recovered in the leachate was notably higher; for pots containing mix InS, around 60%, and for mix 5 more than 90%. This indicated that these two medium types were particularly inefficient, with the majority of their plant available N content being leached rather than taken up by the plants. For mix InS this was particularly interesting because while it consistency leached the lowest absolute amounts of N over the course of the experiment, this was clearly a reflection of its lower plant available N content and not an increased efficiency.

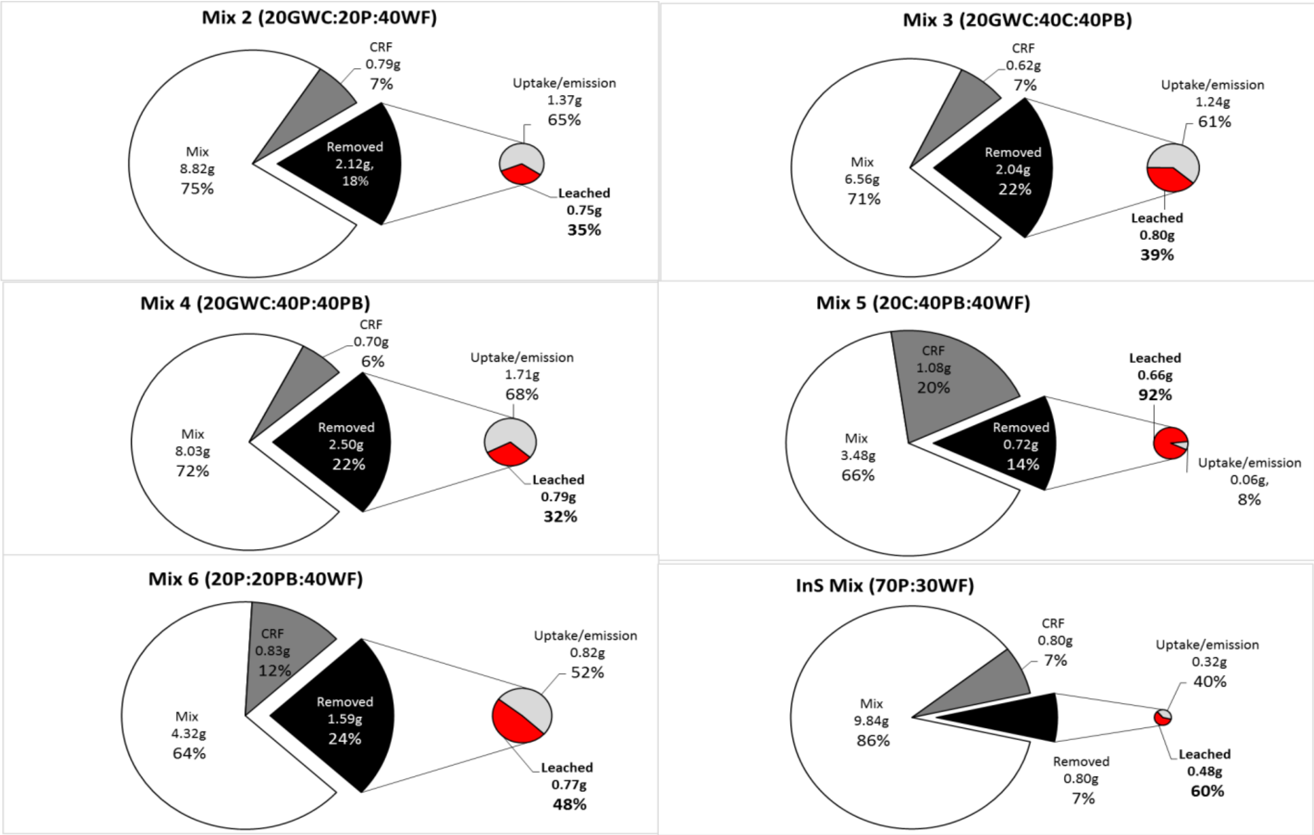

Figure 9. Amount of N (g) remaining and 'removed' (potentially plant available N) per pot at the end of the experiment for the 6 growing medium types. Mix composition by % volume is given on each panel (GWC; garden waste compost, C; coir, P; peat, PB; pine bark and WF; wood fibre). The pie chart on the left of each panel shows the amount (g) and proportion (%) of the starting nitrogen left in the growing medium (mix), the controlled release fertilizer (CRF) and nitrogen which had been 'removed'. This removed pool represents the N which was potentially available for plant uptake during the course of the experiment. The nitrogen in this pool is further broken down in the pie chart on the right into 2 additional pools; the first estimating N taken up by the plant or lost to the atmosphere (uptake/emission) and the second the amount of N recovered in the leachate (leached). The more efficient the media type, the less of the removed or potentially plant available N ended up in the leached pool. Starting N mass is based on analysis of 1 representative sample of each growing media type. Finishing N mass is based on analysis of the mix and CRF at the end of the experiment (n=5).

Figure 10 displays the relationship between shoot dry biomass of Viburnum grown in the 6 growing medium types with CRF and the proportion of the potentially plant available N which was recovered in the leachate. There is a negative, linear relationship (R2= 27%, $p<0.001$) which suggests that the more of the removed N that was lost through leaching, the less was available for plant uptake, resulting in a reduction in the shoot dry biomass produced over the course of the experiment.

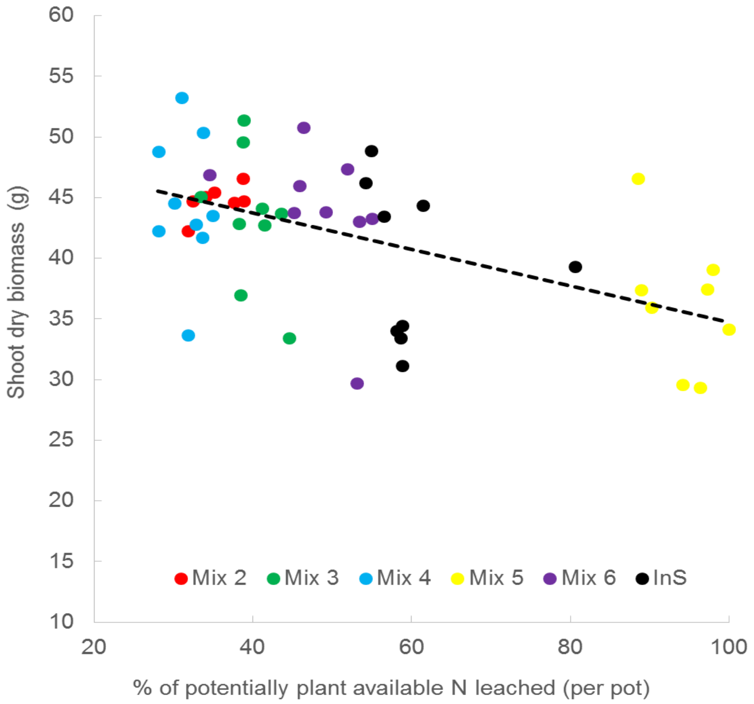

Figure 10. The relationship between shoot dry biomass (g) and the proportion of potentially plant available N (%) that was recovered in the leachate for pots of the 6 growing medium types. Data are fitted with a linear trend line (dry biomass (g) = -0.1496 x % N leached + 49.723). All growing media types have 9 replicates (except mix 2, which has 8 and mix 5 which has 8).

Discussion

This study has two key findings which have both environmental and economic implications for the HONS industry. Firstly, growing medium choice can have a large impact on the absolute amounts of plant macronutrients leached from containers into the environment. As all medium types received the same amount of fertilizer, the inherent nutrient content of some of the component materials e.g. garden waste compost (P, N and K) and coir (K), clearly had an influence on the nutrient content per container and therefore the total quantity of nutrient leached. Notably, mixes 2, 3 and 4 which contained 20% GWC leached around 40% more P and N and 80% more K than mix InS, yet produced plants of equal (or in some cases better quality). This does suggest that some of these mixes were considerably over fertilized highlighting the need for more attention to fertilizer application rates when using a wider range of growing medium component materials. This will not only reduce production costs per pot, but also help to mitigate water quality problems arising from nutrient rich components which may have an additive effect on nutrient leaching.

From a water quality perspective, large differences in the absolute amount of N and P leached between different growing medium types (50% difference in P leaching and a 40% difference in N leaching) are likely to be important. Particularly so, when it is considered that the majority of nutrient loss (at least 50% and in some mixes as much as 80%) occurred in just 7 days. At between 7 and 14 days after potting, N concentrations in the leachate ranged from 135-230mg/l depending on medium type which corresponds to an average daily leaching rate of 19 to 33mg /l per day per pot. For P, the same 7 days saw a cumulative concentration of between 25-34 mg/l, and an estimated daily leaching rate of between 4-5mg/l per pot. If these figures are multiplied by the number of pots on a typical HONS nursery then this early period of heavy leaching does appear to represent a significant water quality issue. The water framework directive (EC, 2006) states the acceptable threshold for N and P in water bodies is 50mg/l and 0.1mg/l respectively. The results presented here are then, in agreement with Adlam *et al*., (2009), who found that P levels discharged from nursery beds often exceed the P threshold. These data also indicate that nurseries may also be at risk of exceeding the N threshold, particularly if potting is followed by a period of intense rainfall. The pollution risk is likely to be significantly higher for some growing medium types compared with others, which certainly warrants further consideration by the industry.

The second key finding of this study was concerned with N efficiency between different growing medium blends. As the six growing media all started with different nutrient content, absolute nutrient leached was not indicative of how efficiently plants were capturing available nutrient over the course of the experiment. This was explored by calculating the amount of N ‘removed’ from pots between the start and end of the experiment. The assumption was made that this ‘removed’ N pool represented the amount of potentially plant available N either lost to the environment or taken up by the plant. As any N lost via leaching was captured and quantified, the proportion of this potentially plant available N leached could be calculated.

The proportion of potentially plant available N leached varied widely between mix types from 32% (mix 4) to as much as 92% (mix 5). While it is well documented that nutrient-use efficiencies in container grown HONS are low because of over-irrigation and over-supply of fertilizer (Lea-Cox and Ristvey, 2003; Owen *et al*., 2008), this work demonstrates how important growing medium choice is on the extent of this inefficiency. More significantly, it also shows that there is a relationship between the proportion of potentially plant available N leached and plant quality. For mix 5 and the largely peat-based mix InS, the data suggest that more than half of all potentially plant available N was leached to the environment. As a result plants grown in these mixes displayed a measurable reduction in vigour both in terms of shoot dry biomass and perceived visual quality.

Determining what may be driving these differences in mix efficiencies is difficult. While the growing media types had distinct physical properties, these differences were not necessarily reflected in their efficiency. This is aptly demonstrated by mixes 5 and 6, the freest draining media, made up of almost identical material components. The only difference being that mix 5 contained 20% coir, whereas mix 6 contained 20% peat; both had an almost identical water holding characteristic (figure 2). However, of the total N removed from mix 5 over the course of the experiment, more than 90% was recovered in the leachate. In contrast, mix 6 lost a relatively modest 48%. So, despite the similarly between these two mixes in physical composition and material formulation, mix 6 leached half as much of its total potentially plant available N than mix 5. Similarly, mix InS, had a very similar water holding characteristic to mix 2, yet leached 25% more of its potentially plant available N. From this evidence, and nutrient content considered equal, physical properties are not a simple predictor of N leaching.

Other factors are clearly important; for mixes 5 and 6, the incorporation of coir in place of peat may have impacted on the cation exchange capacity (CEC) of the mix. While the CEC of the media used in this study were not measured, Mulholland *et al*., 2016 have shown peat to have a CEC an order of magnitude higher than coir. This may well have impacted on the relative ability of the two mixes to retain ammonium ions. With regard to mixes 2 and InS, it seems likely that the incorporation of 20% GWC may have had an important bearing on the relative N efficiency of the two media. When the N content of the growing media was measured at the start of the experiment, both mixes 2 and InS had a similar total N content of *c.* 11g, of which *c.* 2g was water extractable (or immediately leachable; data not shown). However, by the end of the experiment pots containing mix 2 had released 2x (2.1g) more potentially plant available N than pots containing mix InS (0.8g). This suggests that not only did pots containing mix 2 leach proportionally less of their plant available N, but that more of the total N in the mix was made plant available over the course of the experiment. As all three mixes containing GWC were also the most N efficient, this does indicate that this component may have added value, providing a more medium term source of plant available N, which may well help to mitigate the rapid loss of soluble nutrients in the first 7-14 days after potting.

This highlights two important consideration for growers; firstly small changes in growing medium composition can have large impacts on the fate of nutrients and secondly that these impacts are not easy to predict from the physical properties of a growing medium alone. For GWC in particular, it would appear that current analytical measures of N do not accurately reflect the actual amount of fertilizer value this component could bring to a growing medium blend. If this could be more accurately quantified, fertilizer addition could be reduced.

The extent to which the CRF contributed to nutrient leaching was also examined in this study; previous work in containers has indicated that the release pattern of some of CRF products may not match plant demand, particularly early on in the production process (Hershey and Paul, 1982; Huett and Gogel, 2000). The large flush of nutrient leaching seen in this study at between 7-14 days after potting has also been reported in other leaching studies using CRFs under nursery conditions (Huett, 1997; Huett and Morris, 1999). Interestingly, mixes 5 and InS displayed a 7-14 day leaching flush of a similar magnitude regardless of whether CRF was incorporated or not. Indeed, for mix 5 there was no evidence to indicate that pots with CRF were losing more nutrient than those without at this time point. For mix InS, pots with CRF leached more N and P than those without but the differences were relatively modest (48mg N and 7mg P). This would indicate that the majority of nutrient making up this first flush was coming from the growing media rather than the CRF and support the manufacture's stated release time of 2-3 weeks after incorporation. However, it should be noted that in this study, the CRF were dibbled into the containers immediately before potting. This is not necessarily standard practice on UK nurseries; many nursery stock growers purchase growing media with CRF prills already mixed in. This means they may be sitting in the growing medium for several days to weeks before potting occurs. Under such a scenario, the CRF may well be releasing nutrient within the first 7-14 days after potting, particularly if potting is followed by a period of high temperature and/or rainfall. This would be problematic because it would likely lead to excessively high concentrations of nutrients in the containers, especially in less free draining peat-based mixes.

By the end of the experiment, mix 5 had leached a similar amount of P and K regardless of whether a CRF was included in the pot, indicating most of the CRF derived nutrient was taken up by the plant (or at least remained in the pot). For N, pots with a CRF leached about 20% more than pots without. For mix InS, N leached was about 25% higher and P leached 14% higher when pots contained CRF (there was no difference for K). This suggests that around a quarter of N released by the CRF, may have been lost to the environment in mixes 5 and InS. CRFs are an expensive element of HONS production and any nutrient which is simply lost to the environment represents a cost to the grower. A study by Cox, (1993) showed that leaching from CRF was reduced if, rather than receiving one single large application, CRFs were divided into smaller doses and top dressed onto the containers over the course of the production process. This approach would also help to reduce potential CRF nutrient release in the first month after potting when plant demand is relatively low and nutrient concentrations inside the containers are likely to be very high.

Finally, it's important to state here that there are many types of CRF, each brand will have its own release pattern depending on both the type of coating and the source of nutrient salt inside the prill (Mikkelsen *et al*., 1994). Numerous studies under both lab. (Oertli and Lunt, 1962; Huett and Gogel, 2000; Broschat, 2005) and nursery conditions (Cabrera, 1997; Huett and Gogel, 2000) have demonstrated the differences between brands in their relationship with temperature and the subsequent way they release nutrients. Some are capable of withstanding high temperatures (Huett and Gogel, 2000), while others tend to 'dump' large concentrations of nutrients (Handreck and Bunker, 1996). Understanding this difference is particularly important in the context of outdoor container HONS which are subject to large shifts in diurnal temperature. Indeed, in this study, hourly temperatures of above 35°C were routinely recorded inside the containers. Such temperatures are not uncommon, those in excess of 45-50°C have been previously reported on the south side of black nursery containers (Markham *et al*. 2011). These high temperatures combined with periods of heavy rainfall over the summer months mean it's important to identify CRF brands which are more robust at high temperatures. A more prescriptive approach to CRF application may therefore improve nutrient use efficiency. For example by combining brands to provide a pattern of nutrient release better suited to plant demand in combination with different application methods such as dibbling and top dressing.

Conclusions

Growing medium choice can have an important impact on the amount of plant macronutrients lost to the environment and on the efficiency with which plants are able to obtain N from a container environment. These two factors are not complementary i.e. those mixes which leach the largest absolute amounts of nutrient to the environment are not necessarily the least inefficient in terms of the proportion of N available to the plant.

Switching between different growing medium types must be considered from both an environmental and resource-use efficiency perspective.

- Different growing medium blends can have an important impact on both the amount of plant macronutrients lost to the environment and the efficiency of N use within the container
- The amount of N and P leached from containers within the first 2 weeks after potting up is of a magnitude likely to impact on ground water quality
- Nutrient loss from different blended growing media is difficult to predict and will depend on the plant available nutrient content of the component materials combined with their physical and chemical properties
- Higher container temperatures and periods of intense rainfall may lead CRFs to release nutrient in excess of plant demand

Knowledge and Technology Transfer

- 5th October 2016: Presented preliminary findings to growing media industry professionals (at RHS garden Wisley)
- 7th-8th December 2016: Preliminary results presented to growers and industry professionals at two AHDB grower workshops on ‘Hardy nursery stock substrate and nutrition'
- Knowledge exchange to and from AHDB project HNS 193 ‘Nutrient management in hardy nursery stock’
- Invite to present results at Sussex ornamentals grower forum April 2017 and BOPP technical seminar July 2017.

Glossary

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

UoR: University of Reading

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APPENDICES

APPENDIX 1 Progress and objectives – supporting information

Table A. Summary of key presentations and communications

Date	Group	Sector
01/7/2016	Article: AHDB grower (July/August) 'Mixes Measured' pp 14-15	Industry
06/7/2016	Update in AHDB-Hort Ornamental review 2015-2016 'Reducing Peat doesn't spoil plant quality' p19	Industry
01/08/2016	Article in RHS 'The Garden' magazine 'Making a heap of goodness' p58	Public
05/10/2016	Presentation of preliminary data on nutrient losses from different growing media blends to a group of growing medium technical experts	Industry
10/10/2016	'Achieving environmentally sustainable growing media for soilless plant cultivation systems - a review' published in international peer-reviewed journal *Scientia Horticulturae*	Academia/ Industry
07/12/2016	30 minute presentation at AHDB 'HNS substrate and nutrition workshop', HTA offices, Oxfordshire	Industry
08/12/2016	30 minute presentation at AHDB 'HNS substrate and nutrition workshop', Stockbridge Technology Centre, Yorkshire	Industry
11/01/2016	Designed and delivered 3 lectures at 'RHS professional development day on soil management' for professional gardeners	Industry
1/03/2016	Article in RHS 'The Garden' magazine 'managing peat-free media' p34	Public/outreach
15/3/2017	Ran 45 minute workshops on growing media science for school children	Public/outreach
01/04/2017	Article in RHS 'The Garden' magazine 'Biochar's use in garden soils and potting composts' p49	Public/outreach

APPENDIX 2 Overview of peer-reviewed publication

The review paper referenced above in the introduction was published in the scientific peer reviewed journal '*Scientia Horticulturae*' (November 2016, 212:220-234)

The full article can be accessed for free here:

http://www.sciencedirect.com/science/article/pii/S030442381630471X

Achieving environmentally sustainable growing media for soilless plant cultivation systems – a review

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Abstract

Soilless cultivation is recognized globally for its ability to support efficient and intensive plant production. While production systems vary, most utilize a porous substrate or growing medium for plant provision of water and nutrients. Until relatively recently, the main drivers for the selection of the component materials in growing media were largely based on performance and economic considerations. However, increasing concern over the environmental impacts of some commonly used materials, has led researchers to identify and assess more environmentally sound alternatives. There has been an understandable focus on renewable materials from agricultural, industrial and municipal waste streams; while many of these show promise at an experimental level, few have been taken up on a significant scale. To ensure continued growth and sustainable development of soilless cultivation, it is vital that effective and environmentally sustainable materials for growing media are identified. Here we describe the factors influencing material selection, and review the most commonly used organic materials in relation to these. We summarise some of the renewable, primary and waste stream materials that have been investigated to date, highlighting the benefits and challenges associated with their uptake. In response to the need for researchers to better identify promising new materials, we present an evidence-based argument for a more consistent approach to characterising growing media and for a clearer understanding of the practical and economic realities of modern soilless cultivation systems.

APPENDIX 3 Results summary of experimental work

Carried out in 2013/14 to assess the impact of a range of growing media blends on plant quality

The trial compared the performance of 14 blended growing media types, alongside a commercial standard mix (InS). Mixes 2, 3, 4, 5, 6 and InS (highlighted in grey) were selected for the leaching trial described above and were manufactured to exactly the same formulation in both pieces of work (this included the same rate of CRF and additives).

Table B. Ranked performance of *Viburnum tinus* 'french white' in 15 different blended growing media types measured by a). mean visual quality score (1-5) and b). mean shoot dry biomass (SDB) (g) and grown as part of a large experimental trial in 2014. Data are means of 36 replicates per mix. For information only, there was no evidence of any significant effect of growing media type on any either plant quality measure.

a)

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

b)

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

APPENDIX 4 Methods for Determining growing media properties

Table C. Growing media physical and chemical properties determined, the method used and the location at which the analysis took place (in house at RHS garden Wisley, or at an external accredited laboratory; Eurofins Agro, Wageningen, Netherlands or NRM, Bracknell, UK).

Physical Properties	**Method**	**Laboratory**
Air-filled porosity (AFP) %	Modified from (Byrne and Carty, 1989)	Wisley
Water holding capacity (WHC) %	Modified from (Byrne and Carty, 1989)	Wisley
Compacted fresh bulk density (Kg m^3)	BS EN 13040:2007	NRM
Organic matter (%)	BS EN 13041:2011	Eurofins
Water release curve (0.3, -1, -3, -5 and -10kPa)	BS EN 13041: 2011 & (de Boodt and Verdonck, 1972)	Eurofins
Particle size distribution	BS EN 15428:2007	Wisley
Chemical Properties	**Method**	
pH	BS EN 13037:2011	NRM
Electrical Conductivity (EC)	BS EN 13038:2011 (1:5 dilution factor)	NRM
Water extractable N, P and K	BS EN 13652:2001	NRM
Total P and K	BS EN 13650:2001	NRM
Total N	BS EN 13654-2 2001 (Dumas method)	NRM

APPENDIX 5 Physical and chemical properties of the component materials

Table D. Physical and chemical properties of the 5 growing medium component materials a) pH, electrical conductivity (EC, µS.cm-1), air filled porosity (AFP, %), water holding capacity (WHC, %), organic matter (OM) content (%), dry bulk density (DBD, kg·m^3) and fresh bulk density (FBD, kg·m^3) determined for one representative sample of growing media.

	pH	**EC**	**AFP**	**WHC**	**OM**	**FBD**
Component		**µS.cm^{-1}**	**%**	**%**	**%**	**(kg·m^3)**
Coir	6.6	157.2	18.1	65.4	84	377
GWC	8.6	438.3	6.9	65.5	24	856
Peat	4.4	40.8	9.8	68.9	97	351
Pine Bark	4.0	100.8	42.8	27.8	96	290
Wood Fibre	4.4	9.6	39.8	47.8	98	144

Table E. Particle size distribution determined for three representative samples of each growing media type (data are mean values)

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

APPENDIX 6 Physical and chemical properties of the 6 growing media types

Table F. Physical and chemical properties of the 6 growing media types a) pH, electrical conductivity (EC, µS.cm-1), air filled porosity (AFP, %), water holding capacity (WHC, %), organic matter (OM) content (%), dry bulk density (DBD, kg·m^3) and fresh bulk density (FBD, kg·m^3) determined for one representative sample of growing media.

Medium type	Mix composition	pH	EC	AFP	WHC	OM	FBD
	%		µS.cm^{-1}	%	%	%	(kg·m^3)
Mix 2	20GWC:40P:40WF	6.8	573	12	64.9	58.7	436
Mix 3	20GWC:40C:40PB	6.8	677	22.2	52.1	61.7	442
Mix 4	20GWC:40P:40PB	6.1	654	18.1	53.4	66.7	449
Mix 5	20C:40PB:40WF	6.5	373	35.1	45.2	90.0	260
Mix 6	20P:40PB:40WF	5.3	479	32.6	45.6	91.3	255
InS	70P:20WF	5.3	294	15.3	64.1	91.7	365

Table G. Particle size distribution determined for three representative samples of each growing media type (data are mean values)

		Particle Size distribution				
Medium type	Mix composition	<1mm	1-2mm	2-4mm	4-8mm	8-16mm
	%	%	%	%	%	%
Mix 2	20GWC:40P:40WF	53	12	11	13	11
Mix 3	20GWC:40C:40PB	45	13	13	21	7
Mix 4	20GWC:40P:40PB	41	10	14	24	11
Mix 5	20C:40PB:40WF	33	12	18	28	8
Mix 6	20P:40PB:40WF	32	10	15	30	13
InS	70P:20WF	46	10	11	20	12