Growing media developments and nutrient management in hardy nursery stock production

The Rose and Crown, 45 Main Street, Thurnby, Leicester LE7 9PJ

and James Coles & Sons Nurseries Limited, Leicester LE7 9QB and LE7 4XF

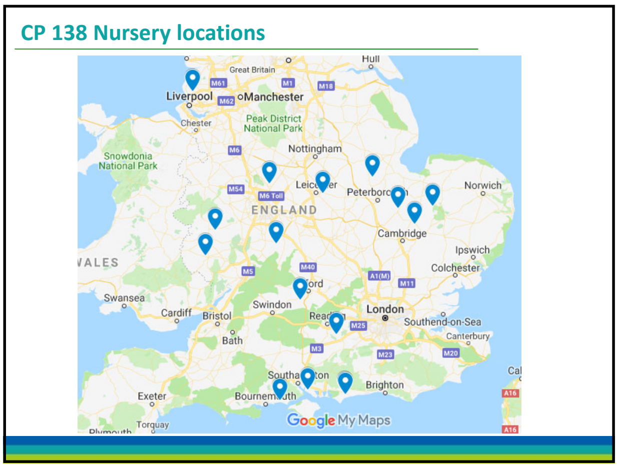
12 September 2019

Workshop programme

Time	Subject	Speaker
10:00	*Coffee, tea and registration at The Rose and Crown, LE7 9PJ*	
10:30	Introduction and nursery overview	Wayne Brough, AHDB and Mark Cade, James Coles and Sons Nurseries
10:35	**CP 138 - Transition to responsibly sourced growing media use in UK horticulture** • Project overview, summary of HNS trials and implications for industry	Dr Sonia Newman, ADAS
11:10	**HNS 200 - Developing nutrient management guidance for hardy nursery stock** • Overview of project and 2019 trials	Dr Jill England and Elysia Bartel, ADAS
11:40	**CP 165 - SceptrePlus herbicide persistence and leachability in peat-reduced and peat-free growing media** • Herbicide performance in new growing media blends	Chloe Whiteside, ADAS
12:00	*Coffee, tea and refreshments*	
12:15	**HNS 193 - Nutrient management in hardy nursery stock** • Maintaining quality in container-grown hardy nursery stock	Neil Bragg, Substrate Associates
13:00	*Lunch, then drive to James Coles and Sons Nurseries, Thurnby site, LE7 9QB*	
14.00	**Demonstrations and displays:** • CP 138 growing media trial • Samples from HNS 200 nutrition trial • Real-time nutrient monitoring equipment evaluated in HNS 193 **Followed by nursery tour and refreshments**	All
15:15	*Travel to James Coles and Sons Nurseries, Gaddesby site, LE7 4XF* **View the field-grown nutrition trial**	All
16:00	*Close and depart*	All

Contents

Transition to responsibly sourced growing media use in UK horticulture
Sonia Newman, ADAS



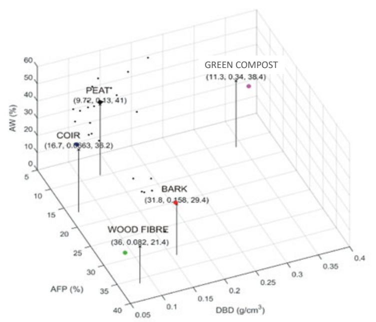
Transition to responsibly sourced growing media use in UK horticulture

Sonia Newman, ADAS

CP 138 Aims

- To construct a model that will produce the desired mixes at least cost.
- To evaluate responsibly sourced growing media blends as alternatives to peat in commercial crop production systems.
- By on-site demonstration and effective communication of the scientific evidence base, increase grower confidence to facilitate the uptake of responsibly sourced growing media for commercial horticulture.

Physical variables



Mulholland et al. (2016) Technical monograph: Growing Media Laboratory Methods. ©ADAS, ISBN 978-1-5262-0393-9, 24 pp.

RSGM Trials

On-site growing media testing and development (Commercial products)

Transition to responsibly sourced growing media use in UK horticulture

Sonia Newman, ADAS

RSGM grower trials 2016 – commercial products

Host	Trial	Duration
Bordon Hill	Bedding	Sown week 16, transplanted week 23
G's	Lettuce Spring	Sown week 14, harvested week 26
G's	Lettuce Early summer	Sown week 26, harvested week 35
G's	Lettuce Late summer	Sown week 32, harvested week 43
New Farm Produce	Strawberries	Planted week 12. Overwintered into 2017
Vitacress	Herbs Spring	Sown week 13, harvested week 20
Vitacress	Herbs Summer	Sown week 31, harvested week 37
Vitacress	Herbs Autumn	Sown week 42, harvested week 49
Wyevale	HNS Finals	Planted week 13 – 20. Overwintered into 2017
Wyevale	HNS Liners	Planted week 16 – 22. Overwintered into 2017
Wyevale	HNS Propagation	Planted week 45. Overwintered into 2017

HNS – Wyevale 2016

Liners and finals:

- 6 species; *Berberis* ,*Choisya, Fuchsia* (finals only)*,* 2 x *Euonymus* and *Viburnum*
- 4 x peat-reduced, 4 x peat-free and 25% peat-reduced control

Propagation:

- *Choisya,* 2 x *Euonymus* and *Viburnum*
- 4 x peat-reduced, 4 x peat-free and peat-free control

Choisya and Fuchsia finals week 18

HNS – Wyevale 2016

Species	Set-up week 2016		
	Liners	Finals	Propagation
Berberis Darwinii 'Nana'	16	16	N/A
Choisya ternata	22	16	45
Euonymus fortunei 'Silver Queen'	18	20	45
Euonymus japonicus 'Green Rocket'	18	20	45
Fuchsia 'Tom Thumb'	N/A	12	N/A
Viburnum davidii	22	12	45

- Liners assessed in week 44.
- Finals assessed in week 44 (*Fuchsia* in week 27).
- Prop assessed in week 20, 2017.

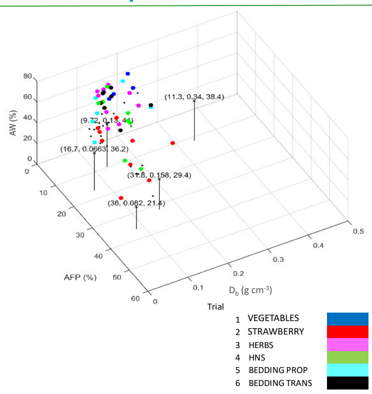
HNS – Wyevale 2016

- No significant differences in the quality of the finals of the 6 species grown in the different growing media.
- The quality of the *Berberis* liners was significantly different ($p = 0.017$). One peat free treatment had lower quality, however this was still marketable.
- No significant differences in the quality of the liners in remaining 4 species.
- No significant differences in the quality of the propagation material for any of the species.

Euonymus japonicus (Green Rocket) finals week 45

Berberis darwinii liners week 45

Commercial blend analysis



RSGM Prototype Blend Trials 2016

Experimental trials
First generation prototype blends

Transition to responsibly sourced growing media use in UK horticulture

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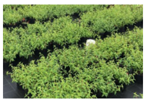
Hardy nursery stock trials

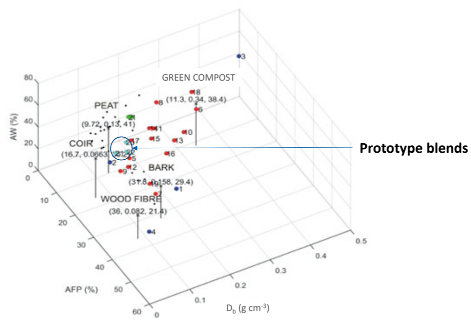
Nursery

2016	2017	2018	2019
			
Wyevale Commercially available blends	**Lowaters** 1st prototype blends	**Darby Nursery** 2nd prototype blends	**Coles Nurseries** 3rd prototype blends

Experimental

			
ADAS & STC 1st prototype blends	**ADAS** 2nd prototype blends	**ADAS** 3rd prototype blends	**ADAS** Model testing

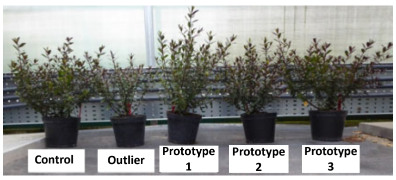
First generation prototype blends 2016



HNS – Experimental 2016 prior to Lowaters trial

Boxworth trial

- *Hebe* 'Midnight Sky' planted into 2 L pots in week 27. Irrigated via ebb and flood.
- 20 treatments (5 x growing media x 4 N / water levels). 5 reps.
- High N plants performed equally well across all blend treatments and were higher quality than low N ($p < 0.001$).
- Outlier blend generally produced smaller and more compact plants.



Hebe **'Midnight Sky', low N, low water, week 42**

Transition to responsibly sourced growing media use in UK horticulture

Sonia Newman, ADAS



RSGM Prototype Blend Trials 2017

Grower trials
First generation prototype blends

RSGM grower trials 2017 – 1st generation prototype blends

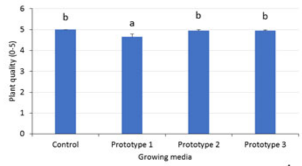
Host	Trial	Duration
Ivan Ambrose	Bedding	Planted week 21, harvested week 24
Frank P Matthews	Fruit tree propagation	Planted week 12. Overwintered into 2018
EU Plants	Strawberry propagation	Planted week 28. Overwintered into 2018
EU Plants	Raspberry propagation	Planted week 15. Overwintered into 2018
Lincolnshire Herbs	Herbs Spring	Sown week 14, harvested week 19-20
Lincolnshire Herbs	Herbs Autumn	Sown week 35, harvested week 41
Lowaters	HNS	Planted week 11-22. Salvia harvested week 22. Other species overwintered into 2018
G's	Mushrooms	Commenced week 29, harvested week 32

HNS – Lowaters Nursery 2017 - 2018

- *Choisya* 'Goldfingers' and *Salvia* 'Hot Lips' potted into 2 L pots in week 11. *Choisya* grown under glass and *Salvia* under polythene.
- *Hebe* 'Heartbreaker' potted into 2 L pots in week 22 and grown under glass.
- Nursery control (100% peat-free) vs 3 peat-free prototype blends.
- Sub-irrigation.
- Assessments completed at 7 week intervals.
- Final assessment completed on *Salvia* in week 22, 2017.
- *Choisya* and *Hebe* left to overwinter, final assessment completed in week 17, 2018.
- Plants assessed for foliage quality, height/growth and root development.

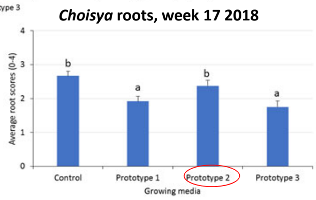
HNS – Lowaters Nursery 2017 - 2018

***Salvia* quality, week 22 2017**



Nursery control (left) and peat-free prototype 2 (right), week 36.

***Choisya* roots, week 17 2018**



Plants grew well in all prototypes, although prototype 2 was slightly better.

HNS – Lowaters Nursery 2017 - 2018

Choisya and Hebe, week 17 2018, and Salvia week 22, 2017.

L-R = Nursery standard, Prototype 1, Prototype 2, Prototype 3.

RSGM Prototype Blend Trials 2017

Experimental trials
Second generation prototype blends

Transition to responsibly sourced growing media use in UK horticulture

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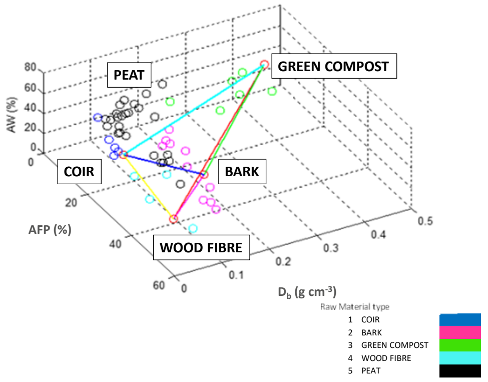
Second generation prototype blends 2017

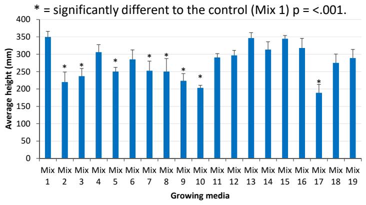


HNS – Experimental 2017 prior to Darby Nursery trial

- *Vinca*, *Lavender* and *Choisya* potted into 2 L pots in week 31.
- Irrigated via ebb and flood as required, 100ppm N.
- 19 growing media treatments. 5 reps.
- Assessed every 4 weeks until week 47, 2017.

HNS – Experimental 2017 prior to Darby Nursery trial

* = significantly different to the control (Mix 1) p = <.001.



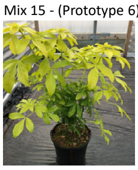
Choisya **16 weeks after potting**

Mix 1 (Peat control)

Mix 6 - (Prototype 4)

Mix 12 - (Prototype 5)

Mix 15 - (Prototype 6)



Mix 18 - (Prototype 7)



RSGM Prototype Blend Trials 2018

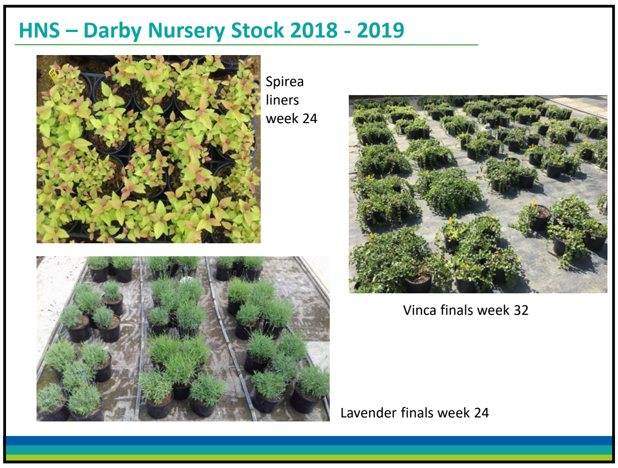
Grower trials
Second generation prototype blends

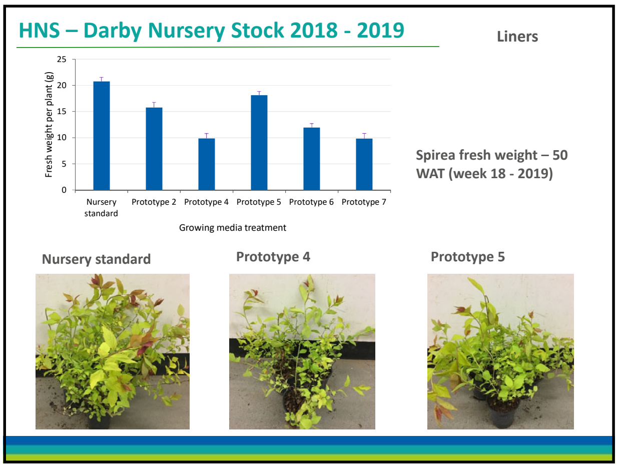
RSGM Grower Trials 2018 – 2nd generation prototype blends

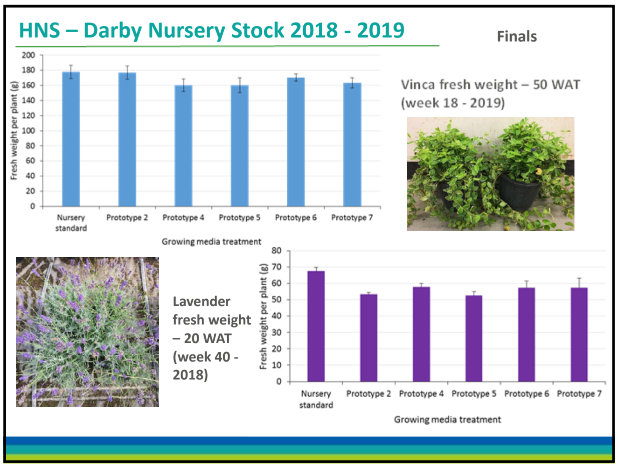
Host	Trial	Duration
Newey Roundstone	Summer Bedding	Planted week 19 & 21, finished week 24
Newey Roundstone	Autumn Bedding	Planted week 39, finished week 44
Delflands	Veg propagation	Sown week 36 & 38, finished week 41
EU Plants	Strawberry propagation	Planted week 28. Overwintering into 2019
EU Plants	Raspberry propagation	Planted week 17. Overwintering into 2019
Darby Nursery Stock	HNS liners & finals	Planted week 20. Lavender finals finished week 40. Other species overwintering into 2019

HNS – Darby Nursery Stock 2018 - 2019

- **Finals:** *Choisya,* Lavender and *Vinca* potted into 2 L pots in week 20. *Choisya* grown under glass, Lavender under polythene and *Vinca* outside.
- **Liners:** Lavender, *Potentilla* and *Spirea* potted into 9 cm pots in week 20 and grown under polythene.
- Nursery control (30% peat-reduced) vs 5 peat-free prototype blends.
- Sub-irrigation.
- Assessments completed at 4 week intervals.
- Final assessment completed on Lavender finals in week 40.
- *Choisya, Vinca* and liners left to overwinter, final assessments will be completed in spring 2019.
- Plants assessed for foliage quality, height/growth and root development. Fresh weight assessed at the end.


HNS – Darby Nursery Stock 2018 - 2019
Spirea liners week 24
Vinca finals week 32
Lavender finals week 24


HNS – Darby Nursery Stock 2018 - 2019
Liners
Fresh weight per plant (g)
Nursery standard
Prototype 2
Prototype 4
Prototype 5
Prototype 6
Prototype 7
Growing media treatment
Spirea fresh weight – 50 WAT (week 18 - 2019)
Nursery standard
Prototype 4
Prototype 5


HNS – Darby Nursery Stock 2018 - 2019
Finals
Fresh weight per plant (g)
Nursery standard
Prototype 2
Prototype 4
Prototype 5
Prototype 6
Prototype 7
Growing media treatment
Vinca fresh weight – 50 WAT (week 18 - 2019)
Lavender fresh weight – 20 WAT (week 40 - 2018)

Transition to responsibly sourced growing media use in UK horticulture
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RSGM Prototype Blend Trials 2018

Experimental trials
Third generation prototype blends

Third generation prototype blends 2018 – 2019

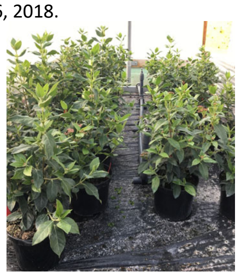
Sector	Experimental trial 2018	Grower hosted trials 2019
Protected Ornamentals	Boxworth	Double H
Hardy Nursery Stock	Boxworth	James Coles and Sons
Herbs	Boxworth	Vitacress

- Third generation blends were designed to test the model.
- 'Novel' materials that were not available to the project team in 2015 have been characterised for their physical properties, and 18 blends were tested at ADAS Boxworth. Three chosen for 2019 grower trials.

HNS – Experimental 2018 prior to James Coles trial

- *Griselinia* and *Viburnum* potted into 2 L pots in week 30.
- Irrigated via overhead sprinkler as required, 100ppm N.
- 19 growing media treatments. 5 reps.
- Assessed every 4 weeks until week 46, 2018.

Griselinia week 30



Viburnum week 46

Transition to responsibly sourced growing media use in UK horticulture

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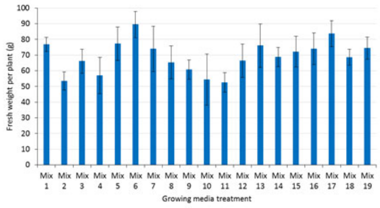
HNS – Experimental 2018 prior to James Coles trial

- Fresh weight – not significantly different to the control (Mix 1) for *Viburnum*.
- Mix 16 and Mix 14 produced best quality plants in *Viburnum* and *Griselinia* after the control.



Viburnum at trial end

Mix 1 (Peat control)

Mix 5 (Prototype 8)

Mix 14 (Prototype 9)

Mix 16 (Prototype 10)



RSGM Prototype Blend Trials 2019

Grower trials
Third generation prototype blends

RSGM Grower Trials 2019 – 3rd generation prototype blends

Host	Trial	Duration
Double H	Pot Chrysanthemums	Planted week 20, finished week 29
Delfland + Elsoms	Veg propagation + field trial	Sown week 27, planted out week 34
New Farm Produce	Strawberry cropping	Planted week 15. Finished week 32
New Farm Produce	Raspberry cropping	Planted week 15. Finished week 34
James Coles & Sons	HNS finals	Planted week 19. Some plants to be planted out at end of trial
Vitacress	Herbs	To be sown week 39

Transition to responsibly sourced growing media use in UK horticulture

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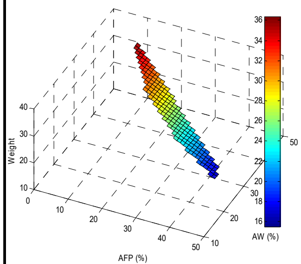
HNS 2019 – James Coles & Sons

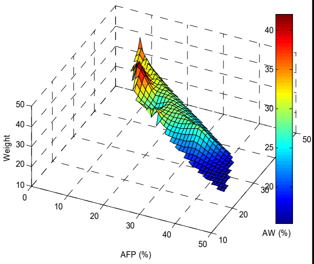
- *Cistus, Griselinia* and *Viburnum* (in peat-reduced liners)
- Liners transplanted into 2 L pots in week 20
- *Cistus* grown outdoors. *Griselinia* and *Viburnum* under protection. All irrigated overhead.
- Nursery standard (peat reduced), 5 peat free prototype blends
- Assessments every 4 weeks.
- Fresh weight shall be assessed at the end of the trial.
- Sub-sample will be planted out to monitor establishment

Developing the model

- All the data gathered so far goes into developing the model.
- The model will be a useful tool which can be used to develop growing media blends with particular characteristics to produce plants of a certain specification.



Predicted fresh weight Chinese Cabbage



Actual fresh weight (mean) Chinese Cabbage

Summary

- Grower trials in 2016 showed that the physical properties of current commercially available peat-reduced and peat-free blends are similar to peat.
- First generation prototype blends performed as well as peat in the experimental trials in 2016. Grower trials in 2017 using these prototypes were successful, echoing the results from 2016.
- The second generation prototype blends performed well on grower sites in 2018, although there were more noticeable differences between the prototypes.
- The results in the third generation experimental trials so far are encouraging, showing that it is possible to take a new material and create blends which will be successful using the modelling approach
- Year 5 (2019) is focusing on strengthening and refining the model through grower trials and experimental trials.

Implications for growers

- Peat-reduced and peat-free blends can be obtained from growing media manufacturers that produce good quality plants
- Very few issues with nutrition or watering were noted during the project
  - Monitoring watering is very important – peat-free is easy to overwater as the surface dries out more quickly than peat
  - Blends may need some nutritional modification, but as noted in CP 095 many will not
- All peat-free blends tested at grower sites were suitable for potting machines
  - Flow rates may need altering to get the best fill
  - Reduce recycling of material where possible
- Have a trial area to test new blends - learn the best practices for the blend
- Store all growing media in a covered, cool, dark place and use as soon as possible

Acknowledgements

- Steve Reed and the team at Wyevale Nursery
- Stephen Carr and the team at Lowaters Nursery
- Alastair Hazell and the team at Darby Nursery Stock
- Mark Cade and the team at James Coles & Sons
- Bord na Mona
- Bulrush
- ICL
- Sinclair
- The ADAS Scientific Support Team
- AHDB Horticulture and Defra

Thank you for listening

@GrowMediaADAS

Improving Nutrient Management in Horticulture

Jill England and Elysia Bartel, ADAS

Improving Nutrient Management in Horticulture

AHDB Horticulture project HNS 200

Dr Jill England, Chloe Whiteside, Elysia Bartel, David Talbot, Neil Bragg, Susie Holmes, and John Adlam

www.adas.uk

Overview

1. Introduction to the project
2. Container-grown nursery stock trial
3. Field-grown nursery stock trial
4. HNS nutrition issues

Introduction

To produce clear nutrient management recommendations for HNS (field and container) growers to help them to optimise nutrient management and minimise the environmental impact of their business activities.

Project steering group

- Alistair Hazell (Darby Nursery Stock)
- James Moffat (Coles Nurseries)
- Susie Holmes (Susie Holmes Consulting Ltd)
- John Adlam (Dove Associates)
- Neil Bragg (Independent Consultant)
- Georgina Key (AHDB)
- Wayne Brough (AHDB)
- Jill England (ADAS)
- David Talbot (ADAS)
- Chloe Whiteside (ADAS)
- Elysia Bartel (ADAS)

Container-grown HNS

Optimise combined controlled release fertiliser and liquid feed regimes for HNS production, developing a 'feed to need' methodology.

Container-grown HNS

Growing media
- 70% peat, 30% woodfibre
- 0.75 kg PG mix 12-14-24

Species
- *Spirea japonica* 'Sparkling Champagne'
- *Prunus lusitanica* 'Myrtifolia'
- *Geranium x cantabrigiense* 'Westray'
- *Tradescantia pallida* 'Purple sabre'

Liquid feed (weekly):
- 10:52:10 (4 weeks)
- 3:1:3.
- 0.5%, 1%, 2%

CRF:
- 12-14m
- 2, 4 & 6 g/L

Analyses:
- Leaf greenness (SPAD)
- Tissue
- Growing media / EC
- Run-off water

Liquid feed fertiliser HNS nutrition trial

Controlled release fertiliser HNS nutrition trial

Field-grown trees

- Establish baseline information on nutrition for field-grown HNS trees.
- Determine the impact of novel fertiliser application methods on plant nutrient status.
- Evaluate crop nutrient assessment methods.

ADAS

Field-grown trees

Species
- *Betula utilis* var. jacquemontii

Nutrient analyses
- From mid-June
- Tissue
- Soil EC
- Leaf greenness (AtLeaf)

Treatments:
1. Untreated
2. Broadcast (nursery standard)
3. Band applied to crop rows

Fertiliser:
- 370 Kg/Ha (20-10-10)

Questions for growers

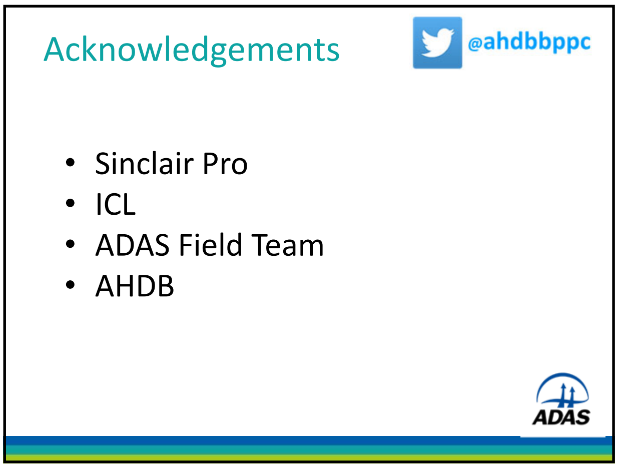
- Specific areas for future research?
- Key species where nutrient data isn't available?
- Specific production systems requiring recommendations?
- Tissue analysis database

Further information

@ahdbbppc

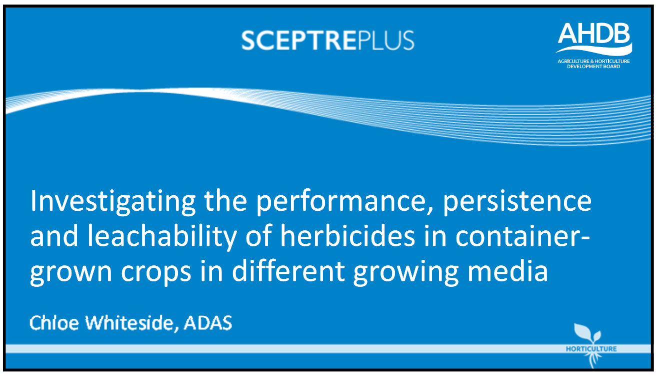
Report: March 2020

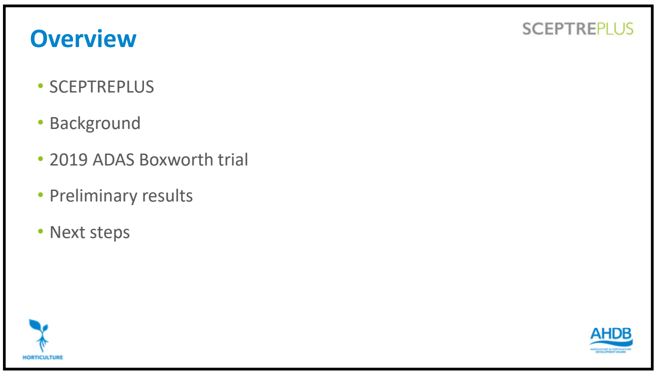
AHDB Horticulture News articles


Acknowledgements
@ahdbbppc
Sinclair Pro
ICL
ADAS Field Team
AHDB
ADAS

Investigating the performance, persistence and leachability of herbicides in container-grown crops in different growing media

Chloe Whiteside, ADAS





Investigating the performance, persistence and leachability of herbicides in container-grown crops in different growing media

Chloe Whiteside, ADAS

SCEPTREPLUS

Background

- Horticulture sectors producing container-grown plants (e.g. HNS) are the largest users by volume of peat-based growing media.
- A significant number of businesses have now reduced the amount of peat in their growing media by 10-50%, using alternative materials such as coir, woodfibre and bark.
- Knowledge of these alternatives in terms of irrigation and nutrition is increasing, but there has been little work carried out on the performance of residual herbicides in such materials, and whether a change in growing media structure can impact leachability.
- To generate label information, trials on crop safety will have been carried out on crops grown in peat-based growing media only. Use via an EAMU however is at growers own risk. Changes in media composition may require changes to herbicide rates of use, to ensure crop safety is maintained.

SCEPTREPLUS

ADAS trial 2019

- One pot trial set-up in May 2019 using 2 L pots, with 4 growing media treatments, 3 herbicide treatments, 3 weed species and 2 sowing dates.
- Each weed species was treated with 1 residual herbicide, which was selected due to its efficacy on controlling that particular weed.
- Selected weeds are all commonly found on container nurseries, both in propagation and final production:
  - Annual meadow grass
  - Hairy bittercress
  - Willowherb
- Two sowing dates:
  - One the day after herbicide application
  - One three weeks after herbicide application

SCEPTREPLUS

ADAS trial 2019

- Growing media treatments:
  - 30% peat-reduced
  - 50% peat-reduced
  - 100% peat-free 1
  - 100% peat-free 2
- Trial located outside with overhead irrigation.
- Assessments on germination, leachate and physical properties of the growing media blends.

Investigating the performance, persistence and leachability of herbicides in container-grown crops in different growing media

Chloe Whiteside, ADAS

ADAS trial 2019

SCEPTREPLUS

		Weed species and herbicide treatment		
Trt No.	Growing media blend	Annual meadow grass	Hairy bittercress	Willowherb
1	30% peat-reduced	Sunfire	Flexidor 500	Dual Gold
2	50% peat-reduced	Sunfire	Flexidor 500	Dual Gold
3	100% peat-free 1	Sunfire	Flexidor 500	Dual Gold
4	100% peat-free 2	Sunfire	Flexidor 500	Dual Gold
5	30% peat-reduced	Untreated	Untreated	Untreated
6	50% peat-reduced	Untreated	Untreated	Untreated
7	100% peat-free 1	Untreated	Untreated	Untreated
8	100% peat-free 2	Untreated	Untreated	Untreated

Herbicides were applied once at label / EAMU rate, in a water volume of 300 L/ha.

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Germination

SCEPTREPLUS

- A germination test was completed on the 3 weed species, prior to trial commencement. Germination was approximately 50 – 60% which was deemed sufficient to start the trial.
- Trial was located outside, with additional overhead irrigation.
- However, germination within the pots from both sowings has been very patchy, in both the treated and untreated plots, which makes it difficult to draw conclusions on efficacy of the herbicides.
- It is possible that the high temperatures in June had an effect on germination.
- Hopefully the trial can be repeated in late autumn, to look at efficacy again.
- Useful data has been gathered on leachate, and this can be related to the structure of the growing media.

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Next steps

SCEPTREPLUS

- Complete physical property testing of the growing media blends and relate to leachability.
- Repeat herbicide application and sowing in late autumn 2019 to see if more information can be gathered on herbicide efficacy and persistence. Examine crop phytotoxicity if deemed to be an issue.
- Consider further work on other herbicides and / or fungicides and insecticides if required.

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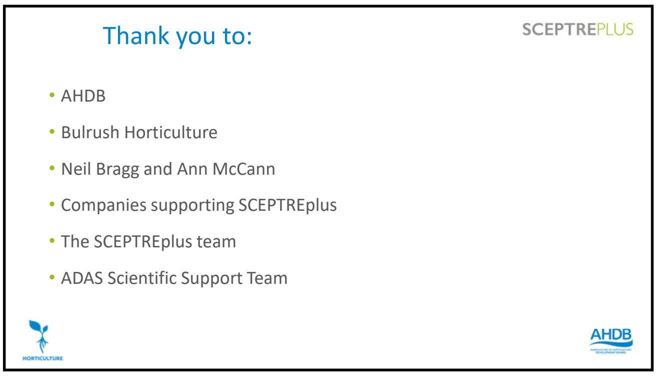
Investigating the performance, persistence and leachability of herbicides in container-grown crops in different growing media

Chloe Whiteside, ADAS



Nutrient management in hardy nursery stock

The problem

How do we judge if a crop has access to a ready supply of available nutrients and how do we assess crop quality?

The project

AHDB funded project - HNS 193: Nutrient management in hardy nursery stock

The trial

Three main geographical locations:

- Greenmount College, N. Ireland
- James Coles and Sons, Leicester
- PCS (Ornamental Research Centre), Ghent, Belgium

Plus some on-nursery testing of techniques at FP Matthews and Osberton Grange Nurseries.

The devices

Four pieces of 'handheld' monitoring devices varying from:

- iPhone app based on colour spectral reflection
- Chlorophyll fluorescence meters
- Sap analysis via ion specific electrodes
- Substrate conductivity measurements

Additionally samples were collected and sent to a laboratory for full analysis, the samples included substrate, leaf tissue and leachate run-off collection.

Overall results

Whilst the devices trialled were intended to be used as a 'handheld, on-site' option for nutrient monitoring, some of the sample preparation meant that plant material had to be collected and effectively taken into a 'laboratory' area for processing. This was mainly a result of:

- Sap extraction from some subjects was very difficult
- Sap colour interference with the results

Of the devices tested, three did produce some trends which could be useful for further interpretation:

- The iPhone app
- Chlorophyll fluorescence meters
- Conductivity measurement of the substrate

There were some clear trends between some of the handheld device results and results from samples sent to the laboratory for full analysis.

Take home messages

The important outcomes were:

- **Need to undertake regular readings from a benchmark/monitor crop**
- **Need to have a dedicated person to achieve uniformity of sampling (a standardised sampling technique is important for result comparison)**

- **Need to be mindful of leachate, especially immediately after potting**
- **Need to consider overall use of pre-mix CRF’s in substrates**
- **Need to have a marker crop on the nursery**

Note within the first six weeks following potting on, the leaf tissue levels may drop dramatically as the plant re-establishes a root system, and analytical results may fall below stated values. Also consider the effects of trimming plants on the potential for increased leaching of nutrients from the substrate in the containers.

Neil Bragg and John Adlam

September 2019

Potential devices for real time nutrient monitoring

Monitoring plant nutrient status has traditionally been done through substrate and/or leaf tissue analysis. Tissue analysis methods have been widely applied to plants due to their reliability for organic nitrogen determination, but they are time-consuming and destructive. Therefore, the focus of project HNS 193 was to test easy-to-use and non-destructive new devices designed for plant nitrogen (N) status estimation.

The project initially tested five different devices that were affordable and easy to use. An additional leaf chlorophyll measurement device was added in the second year.

<u>Nitrogen in plant sap</u>

Plant sap extraction is a destructive method that includes the detachment of the leaf petiole, cutting it into small pieces and compressing it using a garlic press. As the petioles of many ornamental plants are often very small, leaf tissue samples (including the petiole) were used in this project and the leaf sap was analysed.

Two pieces of equipment were used to measure the concentration of nitrate in leaf sap.

Merck Nitrate Test Strip

Nitrate test strips change colour when exposed to nitrate contained in the plant sap sample. The colour can then be compared to a colour chart (subjective method) or be measured by a hand-held reflectometer. The Merck test strips used during this project were those for the detection of nitrate (NO_3). This test strip measures from 0ppm to a maximum of

500ppm NO_3. Merck test strips are quick, easy to use and very cheap (£30.00 per 100 pieces). Test strips measure in nitrates instead of nitrate-N, therefore readings must be divided by 4.43 to find the nitrate-N value.

Horiba Laquatwin Nitrate kit

With this device nitrate levels in plant sap are measured using a nitrate sensitive electrode. This compact nitrate sensor has an operational range from 23 to 2,300mg/L and only needs a few drops of plant sap to generate a reading (enough to cover both electrodes).

However, this technology does have some disadvantages:

(1) It does not measure total N in plant tissue but only NO_3-N

(2) The presence of other ions such as chloride, bicarbonate or nitrite can affect measurements (b)[1]

(3) Frequent calibration is also needed to maintain the accuracy of the sensor (every five samples)

(4) Readings should be made in the shade since direct sunlight can affect the meter

Optical sensing methods

Leaf 'greenness' represents the amount of chlorophyll found in the chloroplasts. Leaf chlorophyll content can be used as an N status indicator, because this is an essential element in photosynthetic protein synthesis. Leaf chlorophyll content increases with N supply and decreases when N is limiting.

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[1] This has always been a problem with ion specific electrodes

atLEAF+

The atLEAF+ is a sensor that measures leaf chlorophyll content in a similar way to a SPAD meter, but has the advantage of being cheaper. It is a non-destructive, hand-held, lightweight and easy-to-use, sensor.

The device works by inserting the leaf into the aperture in the front of the sensor and clicking on the measure button. There are two LED emitters in the upper part of the aperture at two wavelengths, red at 660 nm and near infra-red (NIR) at 940 nm. Light filtered through the leaf is captured by a sensor below it which measures the absorbance of the leaf. The difference in transmission of the filtered wavelengths gives a measure of chlorophyll content in atLEAF+ units.

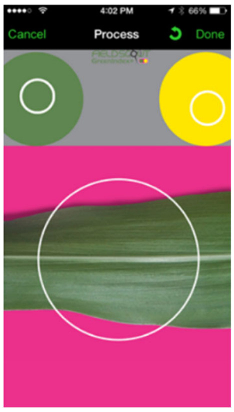
The sensor continues to sample the scanned area as long as the measure button is being pressed. An average value of the measurements will appear when the measure button is released. The device can measure leaves that are up to 0.1 in (2.5 mm) in thickness. Measurements can be stored and easily uploaded to a computer.

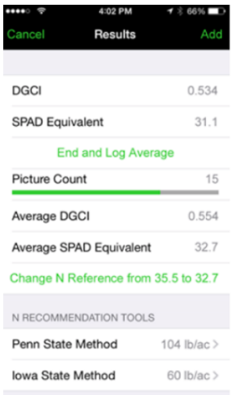
According to literature this sensor is not very effective at collecting readings on leaves with small widths like conifers. Unlike a SPAD meter which makes measurements in a closed chamber that clamps over the leaf, and has a filter to clear other wavelengths in the light spectrum, the atLEAF+ sensor takes measurements in an open aperture and has no filters. This is likely to affect the readings because:

(1) The position of the leaf can vary (closer to the top part of the aperture or to the lower part)

(2) The aperture allows light to reach the sensor diode and interfere with the reading

Fieldscout Green Index App





This app was developed to capture differences in ‘greenness’ between maize leaves. The app captures images using the iPhone digital camera and determines the DGCI (Dark Green Colour Index) of plant leaves (between 0 and 1).

When purchasing this app, growers should also purchase a reference board which is used as a background when taking pictures of the leaves. The green and yellow discs present on this board are known colours (standards) used by the software to calibrate differences in light conditions; the pink background increases contrast and reduces background noise, and the grey colour calibrates the white balance.

Because N status is not the only parameter that affects the greenness of the leaves (water stress, temperature and plant variety also have an impact) the DGCI readings taken in a field must be compared with readings taken in a high-N reference area. Recent studies show that DGCI is closely related to the N content in leaves as well as with SPAD meter readings.

Apogee MC 100

Hand-held chlorophyll meters typically provide a relative indication of chlorophyll content in plant leaves. The Apogee model MC-100 chlorophyll concentration meter measures relative chlorophyll content and outputs an estimate of actual chlorophyll concentration in units of µmol per m^2 of leaf surface.

The MC-100 provides an alternative to destructive sampling techniques for determining chlorophyll concentration. It is less time consuming and labour intensive, and allows for leaves to be measured and monitored over an entire growth cycle. It also allows for rapid replicate measurements of the same leaf, or rapid measurement of multiple leaves.

The MC-100 chlorophyll concentration meter includes custom coefficients to determine chlorophyll concentration for twenty-two different plant species. It also includes a generic equation for use with all plant species (the equation being derived from the data from all twenty-two species). The MC-100 chlorophyll concentration meter consists of two light emitting diodes (one emitting red radiation and one emitting near infrared radiation) with paired detectors and a liquid crystal display (LCD). The meter also includes a USB port for data download to a computer and RS-232 port for use with GPS. The meter measures the ratio of radiation transmittance from two different wavelengths and outputs chlorophyll concentration, which is calculated internally from the transmittance ratio measurement and then displayed on the LCD. In our initial trials this piece of equipment has proven to be very sensitive in identifying the colour change in leaves from the four different CRF rates. The device registered a change in colour before it was visible to the eye and may be capable of detecting nutrient deficiencies at an early stage.

Electrical conductivity (EC) in substrate

Monitoring the N present in the growing media through substrate analysis is a method widely applied in the hardy nursery stock industry. However, sampling growing media is labour-intensive, expensive, and growers have to wait for the results in order to be able to adjust fertiliser regimes.

Procheck and GS3 Sensor Probe

The GS3 sensor from Decagon measures soil moisture, temperature, and electrical conductivity (EC) of the substrate. The probe has three steel needles that improve sensor contact in porous substrates such as peat or perlite. By measuring EC in the substrate solution, the sensor measures the total amount of salts dissolved in pore water. It does not give information on the amount of a specific nutrient. However since the majority of salts in the substrate are macronutrients, EC can be used as an indicator of their presence. The device has proven to follow leaf tissue N levels well as an indicator of nutrient status.

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Calibrating a water-powered proportional dilutor

Figure 1. Proportional dilutors are essential items of nursery equipment permitting the delivery of soluble fertilisers, entomopathogenic nematodes, plant protection products and other liquid concentrates

Action points

- **Calibrate water-powered proportional dilutors every six months, or least on an annual basis, record the results obtained and any actions undertaken as a consequence, such as adjusting the dilution settings on the unit**
- **Ensure any conductivity meter used in the calibration procedure is temperature compensated and calibrated**
- **As part of the calibration process take the opportunity to carry out other checks and inspect the basket filter in the unit head (as appropriate) and the filter in the end of the concentrate extraction pipe to make sure they are clean and undamaged, and also the 'o' ring washers on the valve seats in the unit head to ensure they are still in place**
- **Do not leave any fertiliser solution in the dilutor over the winter period or during long periods of non-use, wash the unit out with clean water prior to storage**

A number of different types of dilutor, of varying levels of sophistication and available dilution ratios, are used on nurseries and farms to apply a range of soluble fertilisers, entomopathogenic nematodes and plant protection products to crops, disinfectants onto hard surface areas, or inject various acids and water treatment additives into stored water sources. This factsheet focuses on the calibration of the water-powered proportional dilutor or dosing pump, traditionally used to apply soluble fertilisers to crops, (Figure 1) and should be used in conjunction with the AHDB video entitled 'Calibrating a water-powered proportional dilutor'.

Introduction

A range of in-line or mobile dilutors are used on nurseries and farms to primarily deliver soluble fertilisers to crops, however depending upon their relative accuracy and flexibility, other materials which need to be applied as high volume drenches to crops, hard surface areas or injected as concentrates into larger volumes of water can also be delivered through them. A water-powered proportional dilutor injects a set amount of concentrate into the water passing through it, the concentrate then mixes with the water before the water pressure pushes the solution out of the unit and into the irrigation network. The dose of the concentrate injected by the unit is proportional to the volume of water entering it. It is important to calibrate such units at least annually to ensure they are still performing within the stated tolerance, wear and tear and damage to key parts can impair their performance.

Equipment needed to undertake the calibration procedure

The following items listed below, and shown in Figure 2, are required to undertake the procedure:

- Scales reading in one gram intervals to 2,000g (2kg), with a zeroed reading facility
- A small measuring cylinder capable of measuring up to 20ml in 5ml intervals
- A range of bottles or beakers with capacities of 500mls
- An electrical conductivity meter which has temperature compensation built into it

It is important to have calibration solutions for the electrical conductivity meter and to calibrate the meter at least every four to six months. Generally electrical conductivity meters are far more reliable and robust than pH meters.

Figure 2. Essential items of equipment that are required to undertake the calibration procedure

Calibration procedure

First of all make up a fertiliser stock solution using any commonly available water soluble fertiliser, or use a readily available fertiliser stock solution which would normally be applied to the crops grown. For example, take a compound water soluble fertiliser such as 20-10-20 (N:P:K) and make up a stock solution containing 100g/l. Dissolving the crystalline fertiliser in the water will reduce the temperature of the solution, therefore it should be left for a short while to reach ambient temperature. If possible when making up the stock solution use warm water (say 15–20°C) to help dissolve the crystals and stir the solution continuously to ensure the fertiliser is fully dissolved.

When measuring out small amounts of liquid it is often easier and more accurate to use scales rather than go by the graduation marks on the container. As one millimetre of water equates to one gram in weight this makes the process straightforward. Zero the scales with the container on them and weigh out the corresponding amount of solution.

Weigh out 10g of the water soluble fertiliser stock solution into a small container using the small measuring cylinder. (The type of plastic measuring thimble supplied with cough medicines is accurate enough for this). Pour the measured amount of stock solution into a clean, dry beaker or bottle capable of holding 500mls plus of solution, already placed on a set of scales which have been zeroed, so that the recorded weight is 10g. Now pour in water from the nursery/farm supply until the reading on the scales is 500g. At this point the beaker contains a diluted solution of 1 in 50 (2%). Measure the electrical conductivity (EC) of the diluted stock solution just created. This will be the highest value recorded and will probably be around 2,100μS/cm^2 (microsiemens) or 2.1mS/cm^2 (millisiemens), depending upon the EC of the water used during the calibration procedure. Record the value obtained.

Take a fresh bottle or beaker and place it on the scales and again zero the reading. Weigh into this bottle 50ml of the previously diluted (2%) solution. This should read 50g on the balance. Add to this a further 50mls of the nursery/farm water supply such that the balance now reads 100g. The solution created has now been diluted to 1 in 100 (1%). Measure the EC of this solution, the value will probably be around 1,400–1,500μS/cm^2 or 1.4–1.5mS/cm^2, and record the value.

Finally, in a clean bottle or beaker, again zeroed on the scales, weigh out 50g of the previously diluted solution (1%) and add to it a further 50mls of the nursery/farm water supply. This solution will now be a dilution of 1 in 200 (0.5%). Measure the EC of this solution, which will be in a range of 700–900μS/cm^2 or 0.7–0.9mS/cm^2, and record the value.

The values can be recorded in a table as outlined in Table 1, noting the EC level recorded against each of the sequential dilution ratios.

Table 1. EC values obtained from the calibration procedure

Dilution ratio or equivalent percentage solution	1:50 2%	1:100 1%	1:200 0.5%
Electrical conductivity value obtained (μS/cm²)	2,100	1,450	825

A graph of the data can then be plotted and used as a calibration curve (Figure 3) as follows:

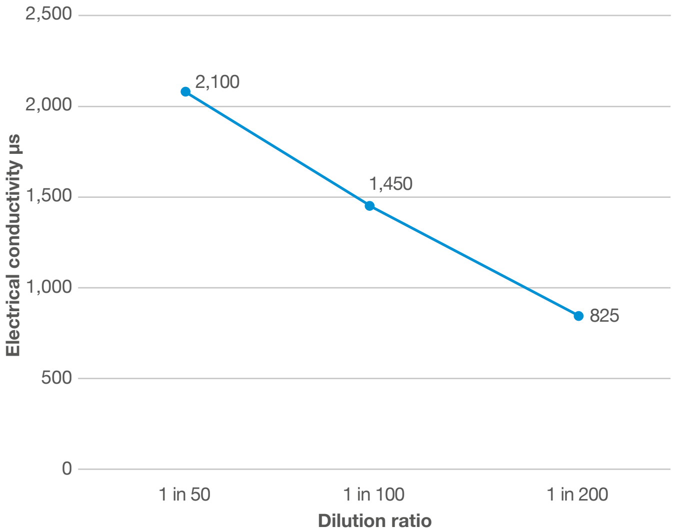

Figure 3. Example calibration curve which can be used to assess the performance of on-site proportional dilutors via the predicted EC levels

The calibration curve created can then be used to test the output of the dilutor at a specific dilution setting. Take the stock solution used to produce the calibration curve and run it through the proportional dilutor to be assessed. Collect the output solution and measure the EC of the solution and compare it to the calibration curve.

For example, at a setting of 1 in 100 (1%) on the proportional dilutor, an EC reading of 1,300μS/cm² may be obtained, where the calibration curve predicted a value of 1,450 μS/cm². To compensate for this, the dilution setting on the dilutor can be adjusted, possibly to 1 in 80 (1.25%). To check this, take a second sample and measure the EC to see if the reading is nearer to the value required. In this way the setting on the dilutor is used as an indicator and the actual accuracy is measured by the use of the EC value. Experience has shown this task to be essential, a regular check is required to verify the correct levels of soluble fertilisers (and other substances) are being applied to crops through the unit.

Note that all the values obtained include the EC of the nursery/farm irrigation water from the source used. Water in the U.K. can have EC values varying between 50μS/cm² and 1,200μS/cm², depending upon source and geographic location. The water used in the calibration procedure described had an EC of 100μS/cm², so all the values shown in Table 1 can only be used for another water source if they were first reduced by 100 and then had the new irrigation water EC value added onto them.

Simple unit maintenance

While undertaking the calibration procedure, it is useful to consider a number of important points regarding unit maintenance:

- Where appropriate check the basket filter in the unit head (Figure 4) to make sure it is clean. It can become clogged with debris in the water source, or concentrate fertiliser crystals can develop on it during periods of low or no use. Ideally when a dilutor is not being used it should be washed out with plain water, via the concentrate feed intake tube, to remove any potential residual fertiliser solution
- Many dilutors contain small 'o' ring washers on the valve seats which close the flow when injecting the concentrate. These 'o' rings can be 'blown off' the valves if the initial water pressure exceeds the unit tolerance levels. These should be checked to make sure they are in place and not damaged. Ideally, upon commencing use of the dilutor, the flow rate of the irrigation water should be gradually increased to working pressure. When in use, the dilutor (if of the piston type) should make a steady audible 'click, click click', as the piston is driven up and down within the unit

Figure 4. Basket filter removed from the unit head of the proportional dilutor ready for cleaning

Author

Neil Bragg, Substrate Associates Ltd

Glossary

Electrical conductance (EC): a measure of the ease by which an electrical current passes through a solution or substance; one millisiemen (mS) equates to one thousand microsiemens (µS).

Further information

AHDB Horticulture factsheets and other information

Factsheet 10/16: 'Sampling methodologies and analysis interpretation for growers of hardy nursery stock'.

Factsheet 06/07: 'Principles of strawberry nutrition in soil-less substrates'.

Factsheet 05/05: 'Nutrition of container-grown hardy nursery stock'.

Wallchart 'Strawberry analysis chart – optimum ranges'.

Transfer of INNOvative techniques for sustainable WAter use in FERtigated crops (EU funded Fertinnowa project), website address – **www.fertinnowa.com**

Acknowledgements

The guidance in this factsheet is based on the content of Bulrush Horticulture Grower Notes GN10. Thanks also go to Russell Woodcock and Gary Woodruffe, Bordon Hill Nurseries, for their time and input into both the factsheet and video dealing with the calibration of water-powered proportional dilutors.

Image copyright

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Watch our 'how to' video for an easy step-by-step visual guide to calibrating a water-powered proportional dilutor. Available from: **bit.ly/ProportionalDilutor**

Produced for you by:

AHDB Horticulture
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T 024 7669 2051
E comms@ahdb.org.uk
W horticulture.ahdb.org.uk
@AHDB_Hort

If you no longer wish to receive this information, please email us on **comms@ahdb.org.uk**

FACTSHEET 05/19, a revision of 05/05

Nutrition of container-grown hardy nursery stock

Figure 1. Lack of an effective fertiliser strategy can lead to longer production times and, in more extreme cases, plant downgrading and even crop losses

Action points

- **Create clear growing media specifications and review them annually**
- **Implement an effective fertiliser strategy for the crops being grown, based on the range of fertiliser products and delivery systems available, to optimise plant development and maintain crop quality (Figure 1)**
- **Regularly monitor the nutrient status of the growing media used on the nursery and sample leaf tissue from crops as required**
- **Consider using one of the on-site crop monitoring devices summarised in this factsheet to generate real-time information about crop nutrient status**
- **Select several key crops to monitor and build up long-term nutrient management records. Such records will assist in the development of a fertiliser strategy and enable nutrient management benchmarking**
- **Understand irrigation water quality and its effect on nutrient availability. Adjust water alkalinity levels as appropriate**
- **Monitor the nutrient status and level of root development in young plants (seedlings, plug plants and liners) prior to potting on. Manage the level of root activity to coincide with potting on so that plants can immediately access available nutrients in the new growing medium**

HORTICULTURE

Background

The production of uniform, high quality, container-grown hardy nursery stock is essential for the future success of the UK hardy nursery stock industry. Selecting growing media that have physical and nutritional characteristics to match crop needs is vitally important to keep production to schedule and avoid downgrading and wastage. Understanding the nutrient release pattern from fertilisers and plant demands throughout the growing season is also paramount to maintain crop quality, avoid potential leaching of nutrients into the environment and to comply with legislation (Figure 2).

Figure 2. Maintaining crop quality requires an understanding of plant nutrient demand and fertiliser performance, taking account of the nursery production systems employed

Increasingly, industry and retailer quality assurance schemes now assess the environmental impact of nursery production systems and demand evidence-based input data from businesses.

Plant quality and longevity after dispatch are also key attributes and must be maintained through to the final customer in terms of retail shelf life and, ultimately, post-planting performance. Optimal crop nutrition throughout the production process is important to ensure plant quality during the latter stages of the supply chain.

This factsheet provides key practical information for making decisions concerning crop nutrition, including:

- The essential nutrient inputs required for quality plant growth
- Creating growing media specifications and an effective fertiliser strategy
- The types of fertilisers and delivery methods available to achieve optimal crop performance
- The influence of irrigation water alkalinity and growing media pH on nutrient availability
- Guidance on monitoring available nutrients throughout the growing season

Nutrient functions within the plant

It is essential to understand the basic functions of the various elements within the plant, because they contribute to key physiological processes that determine plant quality. Knowledge of the symptoms associated with deficiency or toxicity is also important to be able to take appropriate actions to maintain crop quality (Table 1).

Creating growing media specifications, considerations when drawing up a fertiliser strategy and the benefits of nutrient management benchmarking

Growing media specifications are generally based on historical nursery production information and the technical support of the growing media manufacturer. To arrive at the optimal specification there are several factors that must be considered:

- Crop requirements (such as duration of production, growth stage, plant species, plant vigour, etc.)
- Crop production systems in use (use of protected structures, irrigation systems employed, type of standing beds, etc.)
- Supplementary fertiliser practices adopted
- Irrigation water quality, in terms of alkalinity
- Customer requirements and specification agreements

Any growing medium specification should cover the starting pH and electrical conductivity (EC) levels (a measure of the total salts in solution in the medium), the physical constituents used and their particle sizes and the fertilisers incorporated and rates used.

An effective fertiliser strategy should commence with the nutrient content of the growing medium and aim to match nutrient availability with plant demand throughout the production process. The need for supplementary fertilisers will be determined by several factors, including the type and rate of any previous fertiliser used, the crop species grown, cropping duration, the production systems employed, prevailing weather conditions experienced and the agreed customer specifications (Figure 3). Any extra fertiliser should ideally be applied to a schedule, but reactive applications may be required in response to prolonged periods of wet weather or slow customer demand, for example, to prevent such issues affecting crop quality.

Figure 3. The need for supplementary fertilisers will be determined by crop needs, cropping duration, the production systems employed, prevailing weather conditions and any agreed specifications

Table 1. Essential plant nutrients, their function within the plant and known symptoms of deficiency or toxicity

Nutrient	Function in plant	Deficiency symptoms	Toxicity symptoms
Nitrogen (N) Uptake mainly as nitrate, but also possible as ammonium	Protein formation	Deficiency causes poor plant growth and a general yellowing of leaves, commencing with the oldest leaves, which can become red and abscise	High levels of nitrogen lead to soft, lush, blue/green, disease-susceptible growth
Phosphorus (P)	Energy transfer from photosynthesis, root and shoot tip development and flower initiation	Low levels result in general stunting of growth, purpling of older leaves and interveinal chlorosis in some species	Excess can lead to chlorosis in the youngest plant tissue. Ericaceous species are particularly sensitive
Potassium (K)	Regulation of cell water content, sugar transfer via the phloem vessels	Insufficient levels result in middle-aged leaves expressing marginal chlorosis and necrosis	High levels of potassium depress magnesium uptake and lead to apparent deficiency
Magnesium (Mg)	Chlorophyll production	Magnesium deficiency results in interveinal chlorosis of oldest leaves	High levels of magnesium may induce calcium deficiency
Calcium (Ca)	Cell wall formation and cell division	Lack of calcium results in the loss of growing points and collapse and browning of new plant tissue (often linked to high humidity levels)	Toxicity symptoms seldom seen
Sulphur (S)	Constituent of amino acids, proteins and vitamins	Low levels cause a general yellowing of plants, similar to that seen with nitrogen deficiency	Toxicity symptoms seldom seen
Iron (Fe)	Enzyme and chlorophyll production	Iron deficiency results in severe interveinal chlorosis of the youngest leaves (can be associated with high pH and poor root development)	Excessive levels of iron lead to associated manganese accumulation
Boron (B)	Closely related to calcium assimilation in cells	Insufficient levels lead to leaf thickening and downward curling; leaves may become chlorotic, with necrotic spots and lack of apical dominance	High levels of boron cause marginal leaf necrosis on older leaves and can result in flower abortion
Manganese (Mn)	Enzyme systems, especially those associated with nitrogen metabolism	Lack of manganese causes mottled ‘star’ like chlorosis of younger to middle-aged leaves (often linked to high pH)	Excessive levels can cause spotting on older leaves and papery bark (exacerbated by low pH)
Copper (Cu)	Enzyme systems and photosynthesis	Deficiency results in stunting and reddening of leaves; roots may also be poorly developed	High levels will slow growth; new leaves can be pale green and older leaves can develop necrotic margins
Molybdenum (Mo)	Nitrate reduction enzymes	Low levels of molybdenum result in narrow strap-like leaves (usually related to low pH)	Toxicity symptoms seldom seen
Zinc (Zn)	Closely related to phosphorus metabolism	Lack of zinc causes pale, stunted growth	Excessive levels lead to stunted chlorotic growth (sometimes noted on plants under galvanised gutters in structures)

pH levels refer to growing media pH.

See the ***AHDB Crop walkers' guide – Hardy nursery stock*** for a range of deficiency images.

Fertiliser performance and crop development can be subsequently monitored by regular analysis of the growing medium and leaf tissue. The records generated will enable benchmarking of key crops to optimise initial fertiliser rates, determine application timings of additional fertiliser and provide a better understanding of crop nutrient demand throughout the growing season.

Nutrient delivery and types of available fertiliser

There are five methods of nutrient delivery to the crop using a range of fertiliser products. These methods can be used individually, in combination or sequentially.

Base fertilisers

Base fertilisers can be conventional, crystalline, inorganic fertilisers, such as the compound fertiliser 14-16-18 TE (the 'TE' indicating a suite of trace elements accompanying the nitrogen, phosphorus and potassium), or slower release, organic fertilisers, such as 7-7-9, which is based on processed organic residues. There is now also a range of fertilisers that contain nitrogen in the form of methylene urea (38–39% N), which – while not wholly 'organic' – slows down initial release and availability of nitrogen to the crop.

A base fertiliser would normally be added to the physical constituents of a growing medium at the time of production, along with lime and a wetting agent. Typically, such fertilisers are only intended to last four to six weeks and can be easily leached from the growing medium by excessive irrigation or high rainfall after potting, prior to the plants developing an active root system within the new medium. Where used, they are often regarded as a source of short-term nutrients to crops, to which controlled release fertiliser products are added or water soluble fertilisers are applied sequentially afterwards, to supply nutrients over a longer time period.

Base fertiliser is normally added to the growing medium at a rate of 0.5–1.5 kg/m^3. The amount added will vary according to crop species and time of year of potting; for example, lower levels are required for salt-sensitive crops and for autumn potting schedules.

The effectiveness of the inclusion of any base fertiliser depends on the rate of root establishment of the plant following potting. There is considerable merit in pre-conditioning young plants into active root growth prior to potting on, by applying water soluble fertilisers to the plants in advance. Fertilisers, such as 10-52-10, can be used to create a stock solution at a rate of 1 kg/10 L of water and applied for two to three weeks, at 1 in 100, at every watering via a water-powered proportional dilutor to liners and plug plants, ahead of potting on to stimulate root activity.

When moving away from growing media based on peat, there is likely to be a need for additional nitrogen fertiliser. This is because of the potential immobilisation of nitrogen as a result of increased microbial activity in alternative media based on bark and wood fibre. Originally, ammonium nitrate (34.5% N) was used, but the availability of this form of nitrogen to horticulture is now severely limited. Other forms of additional nitrogen that can be used include calcium nitrate (18% N), calcium ammonium nitrate (27% N) and urea (46% N). Note the differing percentage of nitrogen levels in the various forms of supplementary nitrogen; allowance should be made for this when changing source. The nitrogen 'draw-down requirements' of all new physical ingredients used in growing media must be determined ahead of their commercial adoption.

Conversely, growing media containing green compost can contain significant amounts of slower release nutrients; hence, a lower rate of controlled release fertiliser may be satisfactory.

Controlled release fertilisers (CRFs)

For many years, CRFs have been used as the standard method of longer-term fertiliser delivery to a wide range of container-grown hardy nursery stock crops. These products are granulated fertilisers, coated in a resin or polymer that allows moisture to slowly penetrate the coating (Figure 4). The encapsulated fertiliser is then dissolved and diffuses into the growing medium. Generally CRF is added to the physical constituents of a growing medium at the time of production, along with lime, a wetting agent and sometimes a base fertiliser.

It is important to note that fertiliser release will commence as soon as the CRF granules have absorbed moisture, which they will do once the sealed product bag is opened. Fertiliser manufacturers normally state that once mixed into the growing medium, the medium should be used within 14–21 days to avoid accumulation of fertiliser salts from the initial release, which could damage plant roots and lead to nutrient leaching from the medium at first irrigation.

CRFs have different longevities, ranging from three or four months to 18 months, depending upon the thickness of the coating material. Prevailing temperatures also

Figure 4. Different fertiliser products and formulations for use in container-grown hardy nursery stock production. From left to right: prills, granules, powder and pellets

influence the rate of fertiliser release. Product longevities are determined under laboratory conditions, either at a constant temperature of 21°C or 25°C. While these tests are important to provide guidance on the relative release pattern of the different products, they do not always readily translate to commercial production conditions. For example, there is often a considerable difference in growing media temperature between containers situated on the southern facing edge of a production bed and those in the centre of the bed, which can affect uniform fertiliser release across the whole crop. However, coating technologies are constantly evolving; for example, some products have secondary coats to prevent initial release from the granules, to help reduce the impact of such conditions.

In terms of the CRF product required and the rate at which it should be incorporated into the growing medium, several factors must be considered:

- The plant species grown and its relative vigour or salt sensitivity
- The stage of production, propagation through to potting on established plants
- Time of potting; spring/summer versus autumn/winter
- Production timescale in terms of time to next potting or marketing
- Cropping systems used, including the use of protective structures and the type of irrigation system employed

Generic recommendations for the use of CRFs are provided in Table 2.

As well as incorporation, CRFs can also be dispensed or 'dibbled' into the growing medium at potting. With this technique, the desired amount of fertiliser is dispensed into each container at the base of the drilled planting hole during machine potting (Figure 5). This approach allows changes in fertiliser rates to be made more easily. Dibbling also permits a 10–20% reduction in the rate of fertiliser applied, relative to incorporation during production of the growing medium. Furthermore, when coupled with careful water management and good nursery hygiene, dibbling helps to reduce the development of moss and liverwort on the surface of the growing medium.

Figure 5. A CRF dispenser can deliver a measured amount of fertiliser into the base of the drilled planting hole when machine potting

Table 2. Generic recommendations for the use of different CRF types in growing media

Typical use	CRF type	Rate range (kg/m^3)	Comments
Propagation in cell trays	Mini granules	0.5–1.0	Very difficult to achieve good distribution the smaller the plug tray cell size
Spring-potted, very short-term perennials	Mini granules or very short-term depending upon container size	1.0–2.5	Very short-term equates to three to five month type products. Lower rates for protected crops
Herbaceous perennials including alpines, heathers and herbs	Short-term	1.0–3.0	Short-term equates to five to six month type products. Lower rates for protected crops. Consider the use of 'dibble' application for subjects such as heathers
General shrubs, including climbers, conifers and shrubs liners	Medium-term	2.0–4.5	Medium-term equates to eight to nine month type products. Consider using species-specific CRF where available
Trees, shrubs and long-term crops	Long-term	2.0–6.0	Long-term equates to 12 to 18 month type products. Use lower rates if supplementary fertilisers are to be used

Several products now offer a range of ratios of major nutrients within each longevity type. For example, 'fast-start' blends with more nitrogen and 'high K' blends with less nitrogen and more potassium, where excessive leafy growth is unwanted (for example, with herbaceous plants).

Always refer to the manufacturer's technical literature and recommended CRF rates.

Reduced CRF rates are recommended for young plants/liners and for autumn potting.

For specific situations that may require additional fertiliser release or prolonged longevity, there can be merit in blending CRF products from different manufacturers to achieve the desired result.

Most CRF products now contain trace elements, negating the need for the separate incorporation of fritted trace elements for most crops.

Slow release fertilisers

Slow release fertilisers, which can be fully or partially derived from organic materials, all rely on the microbial mineralisation process to convert the organic source of nutrients to a mineral equivalent that can then be taken up by plants. The mineralisation process is determined by the presence of a microbial population (or the speed at which a population can develop to meet the nutrient demands of the plant), the correct moisture level and sufficient temperatures to allow the microbial population to flourish.

Traditionally, when applied to soils, such fertilisers have performed satisfactorily because the mineralisation process is driven by the presence of complex microbial populations and there is a sufficiently large nutrient buffer in the soil to overcome any short falls. In growing media made up of relatively inert materials, the mineralisation process may be slow and unreliable in terms of meeting plant requirements for mineral elements. Even adding such fertilisers to peat-based growing media can be problematic because, while some of the microbes required are present, others have to build up and incomplete mineralisation can lead to the accumulation of toxic amounts of specific elements.

As a result, such fertilisers are normally used as top-dressings, the aim being to gradually supply mineral elements to maintain plant growth. Although a number of products contain a range of nutrients, some can contain high levels of a single element, such as nitrogen, so correct product selection is important.

Water soluble fertilisers

Such fertilisers are normally dissolved in water to make a stock solution and are then applied through a water-powered proportional dilutor at a set dilution ratio to the crop (Figure 6). Straight fertilisers, such as calcium nitrate, or compound fertilisers, such as 18-10-18, can be applied in this manner.

Water soluble fertilisers allow greater control of plant growth than a CRF-based system. They may also be employed where the CRF within the growing media is running out; for example, if plants are kept on the nursery longer than anticipated, or where excessive leaching of nutrients has occurred and immediate nutrition is required.

Water soluble fertilisers containing different ratios of nutrients can also be used to help manipulate growth. For example, a high nitrogen, water soluble fertiliser, used carefully during the growing season, can provide a timely boost to crop growth and colour. Similarly, the delivery of a high phosphate, water soluble fertiliser to young plant material prior to potting on will speed up establishment (Table 3).

Figure 6. Typical water-powered proportional dilutor used for the application of water soluble fertilisers to crops

Table 3. Example water soluble fertilisers for shrubs and herbaceous crops and suggested growth stage at application

General fertiliser ratio ($N-P_2O_5-K_2O$)	Growth stage at application
1-1-1	Young plant establishment, when phosphorus demand is higher
3-1-3 or 4-1-4	Vegetative growth stage during spring/summer
3-1-6	Lower nitrogen/higher potassium fertiliser for flowering or during the later stages of growth in late summer/autumn

Fertiliser strategies based on the application of water soluble fertilisers are better suited to crops grown under protection, where the environment can be controlled; long periods of rainfall can be problematic, leaching out nutrients and negating opportunities to replace them. The suitability of water soluble fertilisers is also determined by the efficiency of the irrigation system employed on the nursery – overhead systems are usually less efficient than drip irrigation, for example.

Overhead application of a dilute fertiliser solution can also exacerbate liverwort and moss development on the surface of the growing medium and on production beds and pathways. Plants grown solely with water soluble fertilisers will also have very little retail shelf life once they leave the nursery and regular application of fertiliser ceases.

With any type of water soluble fertiliser, the concentration of nutrients applied can be varied, either by adjusting the strength of the stock solution, or – more commonly – by adjusting the injected dilution ratio on the water-powered proportional dilutor.

Specialist fertilisers are also available for use with hard or soft irrigation water; the former containing phosphate in a form more available at higher pHs and the latter supplying extra calcium.

Supplementary fertiliser applications

Where nutrient levels are low because the CRF is running out or where excessive leaching of nutrients has occurred over winter and it is not practical to apply a water soluble fertiliser, plants can be top-dressed in the early spring using short-term CRFs or compound fertilisers. Fertilisers can be applied manually or via an applicator that automatically dispenses a set amount of fertiliser onto the growing medium surface of each container (Figure 7).

Short-term CRFs

Supplementary feeding with a short-term CRF, either top-dressed loosely onto the surface of the growing medium or by the use of CRF plugs (clusters of prills) inserted into the growing medium, is more expensive than the other options, but useful for long-term/high-value crops that may not be sold until later in the year. Top-dressing should be carried out during March to allow sufficient time for nutrient release to take effect.

Compound fertilisers

Top-dressing with a powder or granular inorganic, compound fertiliser will supply nutrients for up to six weeks and, if the growing medium surface is moist, nutrients will rapidly become available to the plant. Nutrient release from organic-based fertilisers is usually slower and will take a little longer.

It is important to distribute the fertiliser evenly, while avoiding placement immediately around the stems of plants because this can cause damage (Figure 8). If production beds are located in exposed areas and plants are prone to being blown over, then any loose fertiliser application may be lost to the crop. As with the overhead application of water soluble fertilisers, nutrient application directly to the growing medium surface can encourage liverwort and moss growth.

Figure 7. A typical top-dressing applicator for use with container-grown crops

Figure 8. Application of a fertiliser top-dressing to the surface of the growing medium, avoiding contact with the stem base

Foliar fertilisers

For some crops it may be worth considering the use of a foliar fertiliser to boost crop performance, particularly ahead of any re-potting operations. Several proprietary foliar fertilisers are available, but some crops, like *Camellia* or *Rhododendron*, have leaves that are too waxy to absorb such fertilisers. Some foliar fertilisers can be tank mixed with routine fungicide applications; product labels and manufacturer's technical recommendations should be checked before doing so.

A summary of the types of fertiliser products available for use in the production of hardy nursery stock can be found on the AHDB website at **ahdb.org.uk/knowledge-library**

Factors affecting nutrient availability in the growing medium

Irrigation water alkalinity

Having detailed knowledge of the quality of the irrigation water applied to crops on the nursery is important, especially the alkalinity level of the water. Alkalinity is a measure of the bicarbonate content of water and can be categorised from very soft (0–50 ppm bicarbonate) to extremely hard (over 300 ppm). Pure rainwater has very low alkalinity, whereas mains or groundwater that has percolated through limestone or chalk geology will be saturated with carbonates to the extent that plants are lime washed at each irrigation. Higher levels of irrigation water alkalinity increase the risk of the growing medium pH rising over time and this will, with the exception of molybdenum, limit the availability of trace elements to the plants.

Acid treatment to adjust irrigation water alkalinity

Where the alkalinity of irrigation water is above 200 ppm bicarbonate, it is worth considering treatment to reduce the level (Table 4). Treating irrigation water with strong mineral acids, such as nitric acid (60%), to reduce the alkalinity to 60–90 ppm residual bicarbonate will avoid pH changes in the growing medium (Figure 9). However, the injection of nitric acid will also mean that the applied irrigation water will have a nitrate loading of around 40–50 ppm nitrogen, which may require other fertiliser treatments to be modified as a result.

Other strong acids, such as phosphoric acid, can be used to reduce the alkalinity of water. Citric acid may be used where the water alkalinity is less than 200 ppm. Several water soluble fertilisers are available that contain urea phosphate, which is extremely acidic, to reduce the alkalinity of the water supply.

Note that, where rainwater is used as the main source of irrigation water, it may be necessary to supplement the crop with calcium and magnesium. This is because, apart from the limestone added to the growing medium and the limited level of magnesium in some fertilisers, the water supply is often the usual source of both elements. Additional calcium and magnesium can be supplied using water soluble fertilisers, or within the growing medium via the addition of materials such as gypsum or kieserite.

Table 4. Water type categorisation and suggested treatment methods

Water type	Alkalinity (ppm or mg/l)	Need for treatment	Possible method of treatment
Very soft	0–50	Worth considering	Addition of extra calcium to the growing medium
Soft	51–125	None	None
Hard	126–200	Worth considering	Acidifying water soluble fertilisers or mild acid
Very hard	201–300	Yes	Blend water or inject strong acids
Extremely hard	>301	Yes	Blend water, inject strong acids. Find alternative source if possible for ericaceous crops/propagation

Figure 9. Automatic acid dosing equipment and acid storage to adjust irrigation water alkalinity

Growing media pH

The availability of nutrients in growing media varies with pH and many nutrients are available to plants at the required level only within certain pH ranges. As a guide, for most peat-based growing media, a starting pH of 5.0–5.5 is preferred for general shrubs and 4.5–5.0 for ericaceous species. Some *Malus* and *Prunus* fruit tree species require a higher pH than general shrubs (5.5–6.0 is recommended) to avoid bark splitting (Table 5).

A pH below 4.5–5.0 for non-ericaceous plants will cause problems associated with insufficient calcium and excess availability of trace elements such as iron, manganese and zinc, causing toxicity. If the pH is too high – that is, greater than 6.0–6.5 – many nutrients, particularly iron (Figure 10), manganese and phosphorus, become less available.

Many of the emerging peat replacement materials such as bark, coir and green compost all have initial pH's above 7.0. However, unlike peat which has a relatively high buffering capacity these new materials have low buffering capacities and hence their ultimate influence on the pH of media mixes is very limited.

Table 5. Desired pH ranges by cropping groups

Cropping group	pH range*	Comments
Ericaceous	4.5–5.0	Plants are generally inefficient at taking up iron, but are sensitive to high levels of available phosphorus
General nursery stock	5.0–5.5	Adequate for most species
Malus and *Prunus* species	5.5–6.0	These plants are subject to manganese accumulation at lower pHs and this can lead to bark splitting

*For peat-based growing media using the 1:5 water extraction analysis method.

Note that where peat is replaced in the growing media, only the peat fraction requires lime; above 50% peat replacement, alternative sources of calcium and magnesium are required.

Figure 10. Severe induced iron deficiency in *Hydrangea*

Monitoring crop nutrition

An awareness of the various symptoms of plant nutrient deficiency and toxicity is important so that appropriate corrective actions can be undertaken. However, by the time symptoms are visually obvious, crop quality can already be affected and it can take longer for corrective measures to take effect. Routinely monitoring the growing media via sample analysis at external laboratories can highlight potential problems at an earlier stage and minimise downgrading and crop losses. As part of AHDB-funded project HNS 193 ***Nutrient management in hardy nursery stock***, several real-time, hand-held monitoring devices were assessed for their practical application on nurseries. The potential of these devices is summarised in this factsheet.

Growing media analysis for nutrient status

Analysis of both freshly delivered growing media and the media from growing crops is useful to monitor pH and general nutrient status, particularly for crops included in any nutrient management benchmarking, new plant species in cultivation, or following changes to growing media specifications. A minimal monitoring programme for spring-potted, overwintered, container-grown nursery stock should be based on pH and nutrient analysis in mid-summer (available water soluble nutrient analysis), early autumn (total water soluble nutrient analysis) and late winter/early spring (total water soluble nutrient analysis).

For protected crops, for which nutrient levels may fluctuate, and for salt sensitive species, a strategy based on more frequent growing media analysis may be necessary; for example, at monthly or six week intervals, particularly for the EC level. This can be especially pertinent where capillary irrigation systems are used because salts may gradually build up in the growing medium and within capillary matting. The overall nutrient status of a growing medium can be broadly determined from the EC (Table 6). UK analytical laboratories usually express EC in microsiemens (µS) per centimetre. Millisiemens (mS) per metre is also sometimes quoted (100 µS/cm = 10 mS/m). Care must be taken when comparing analysis results from laboratories that use different analytical methods.

Table 6. Maximum suggested electrical conductivity levels by crop type

Crop type	Maximum EC µS/cm*
Salt-sensitive young plants – ericaceous rooted cuttings, plug plants and liners	150
Other young plants – liners, bare-root herbaceous plants, alpines	300
Established herbaceous plants and shrubs	400
Vigorous shrubs and trees	500

*Suggested levels for peat-based growing media, using the 1:5 water extraction analysis method.

Monitoring available nutrients

To obtain an indication of available water soluble nutrient levels within the growing medium, analytical laboratories use a water extraction method (peat-based media only). Where CRFs are used the analysis will only measure the nutrients in solution at the time of sampling, if nutrient release from the CRF granules is balanced by crop uptake, only low levels will be detected.

Similarly, where greater slower release nutrient sources are present – for example, in a medium containing green compost – this will underestimate the potentially available nutrients. Hence different chemical extractants, rather than water, are more appropriate.

Monitoring remaining CRF nutrients

Total water soluble nutrient analysis (analysis of a macerated sample of the growing medium), can be more helpful at certain times of year because it provides information on the percentage of original nutrients still contained within the CRF granules. This can be particularly useful to assess total nutrient levels before the winter period and prior to supplementary fertiliser applications in spring.

Leaf tissue analysis for nutrient status

Leaf tissue analysis can be useful to diagnose nutritional disorders, particularly suspected trace element deficiencies/toxicities for which growing media analysis is not so easy to interpret, and to collect long-term data from key crops for benchmarking. A general range of values for each element is provided in Factsheet 10/16 ***Sampling methodologies and analysis interpretation for growers of hardy nursery stock***, along with useful references to further information to aid value interpretation. Such values should still be tempered in relation to the season, crop species in question and the growing conditions experienced.

Use of on-site crop monitoring devices

Hand-held devices for measuring growing media pH and EC are useful for problem diagnosis, monitoring new crops or batches of growing media and to check whether or not supplementary fertilisers need to be applied. However, AHDB-funded project HNS 193 identified several new devices, including an iPhone application, which showed potential for monitoring the nutrient status of a crop in real-time, with equipment output being correlated to leaf tissue nitrogen levels determined via laboratory analysis. A device for measuring growing media EC was also linked to leaf tissue analysis results.

There are several important points to remember when using the devices summarised in this factsheet:

- Select and mark a typical plant within the crop from which to take sequential readings
- Dedicate one person to undertake the assessments and try to take readings at the same time of day at each recording
- In terms of plant assessments, it is difficult to obtain chlorophyll readings from conifers, the leaf colour measuring device should not be used on variegated plant species and sap-based devices require fleshy sample leaves
- Clearly label samples to be sent away to analytical laboratories
- Note any crop trimming, irrigation events or water soluble fertiliser applications that may have taken place earlier in the day if using EC measurements

Note that device output is specific to the recording site only; it is not advisable to use data from other sites.

During the first year of monitoring using these devices, laboratory analysis will also be required to correlate against the crop values recorded.

Leaf chlorophyll sensing

The sensor within the atLEAF+ device measures two specific light reflectance levels and gives an output in the range 0–100. Correlation of the device output to leaf tissue nitrogen levels can be mapped over time (Figure 11).

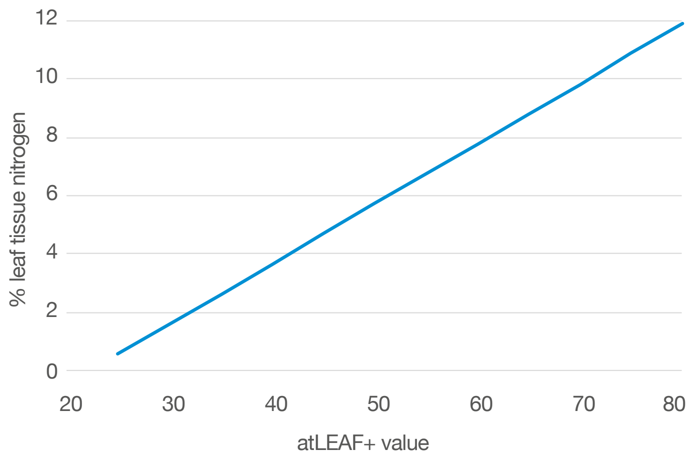

Figure 11. The atLEAF+ leaf chlorophyll measuring device and the correlation between the device output and leaf tissue nitrogen levels for *Tradescantia*

Leaf colour assessment

FieldScout GreenIndex is an iPhone application that uses the phone's in-built camera and a colour calibration board to assess leaf colour. It allocates a 'dark green colour index' of 0–1. As with the atLEAF+ device, correlation of the device output to leaf tissue nitrogen levels can be mapped over time (Figure 12).

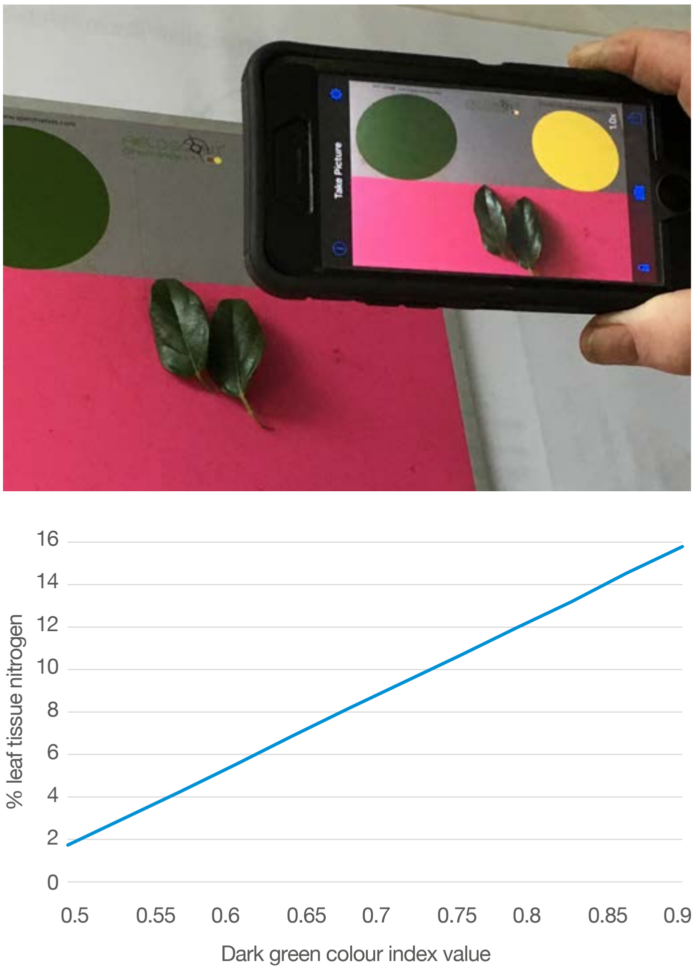

Figure 12. The FieldScout GreenIndex iPhone application in use and the correlation between the device output and leaf tissue nitrogen levels for *Tradescantia*

Leaf sap testing

A nitrate strip test and LAQUAtwin nitrate device can both be used to directly measure nitrogen levels in leaf sap (Figure 13). A garlic press should be used to extract sap from a selected fleshy leaf (it is not easy to obtain leaf sap from some plant species). Both devices show leaf nitrate nitrogen content only, not total nitrogen as calculated via laboratory leaf tissue analysis. Coloured plant sap can affect the reading obtained.

Figure 13. Nitrate strip test and LAQUAtwin nitrate sensor

Measuring growing media electrical conductivity

The Decagon ProCheck device and GS3 sensor provide an EC reading of the growing medium (Figure 14). The growing medium should be assessed prior to any water soluble fertiliser application or irrigation event and before crop trimming (where scheduled) because such actions can affect results. Taking multiple readings from the growing medium will help to minimise random output from CRF granules. Bear in mind that the background EC of the irrigation water used on the nursery may provide higher readings than those generated by laboratory analysis.

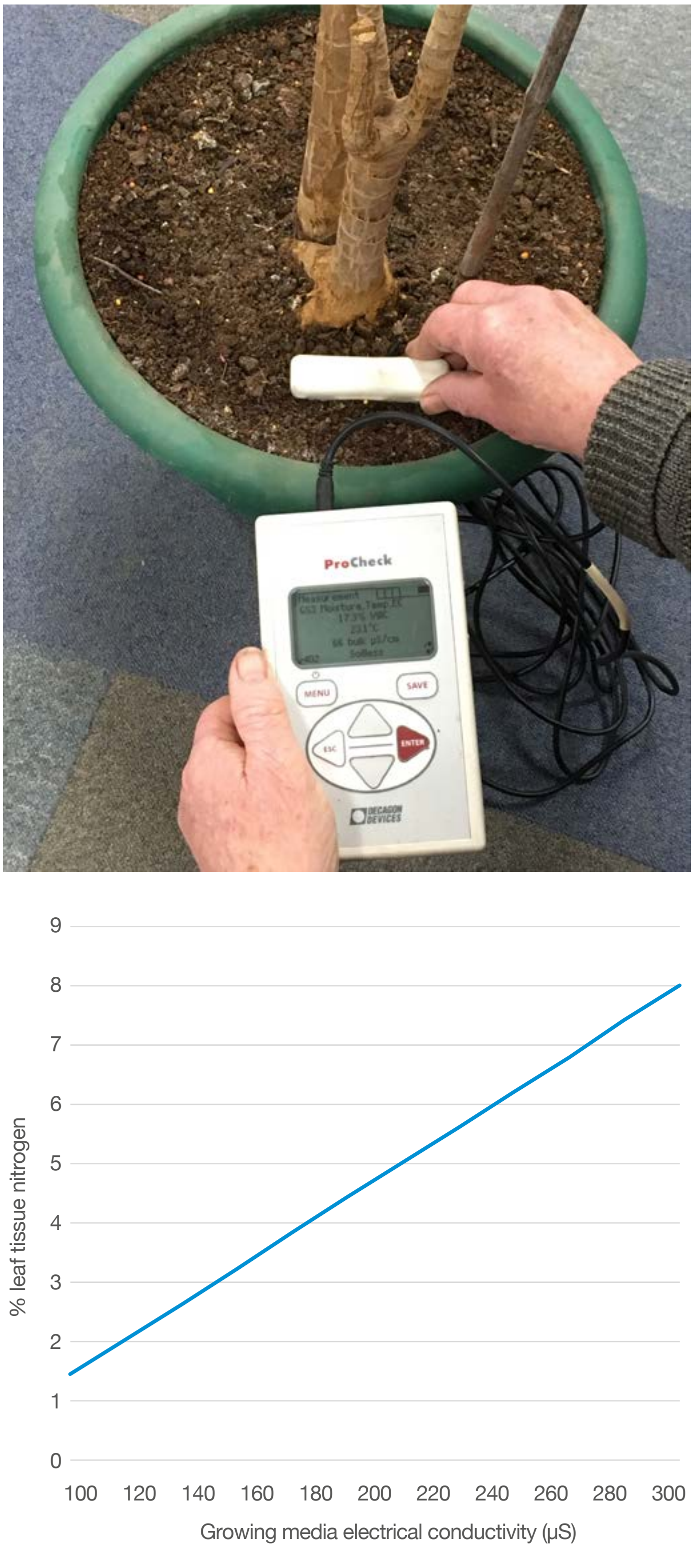

Figure 14. The Decagon ProCheck and GS3 sensor and the correlation between growing media EC and leaf tissue nitrogen levels for *Buddleia*

Authors

Neil Bragg, Substrate Associates Ltd and John Adlam, Dove Associates

List of UK laboratories offering analytical services and suppliers of the on-site monitoring devices

UK laboratories

Anglian Soil Analysis
www.angliansoil.co.uk

Eurofins UK
www.eurofins.co.uk

NRM Ltd
www.nrm.uk.com

Yara
www.yara.co.uk

On-site monitoring devices

atLEAF+ device
www.atleaf.com

Decagon ProCheck and GS3 sensor
www.decagon.com

FieldScout GreenIndex application
www.specmeters.com

LAQUAtwin nitrate device
www.horiba.com

Nitrate strip test
www.merckmillipore.com/gb

Further information

AHDB Horticulture factsheets and publications

Factsheet 13/18 ***Calibrating a water-powered proportional dilutor***

Factsheet 17/17 ***Measuring and improving the performance of overhead irrigation for container-grown crops***

Factsheet 10/16 ***Sampling methodologies and analysis interpretation for growers of hardy nursery stock***

Crop walkers' guide – Hardy nursery stock

AHDB Horticulture grower summaries and reports

HNS 193 ***Nutrient management in hardy nursery stock***

HNS 189 ***Study to review and improve nutrient management in container-grown hardy nursery stock***

HNS 96a and 96 ***Investigations into the controlled release fertiliser requirements of heathers***

HNS 95 ***Investigation into the controlled release fertiliser requirements of climbers***

HNS 43a–f ***Investigations into the controlled release fertiliser requirements of container-grown nursery stock and herbaceous perennials***

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Produced for you by:

AHDB Horticulture
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T 024 7669 2051
E comms@ahdb.org.uk
W ahdb.org.uk
@AHDB_Hort

If you no longer wish to receive this information, please email us on **comms@ahdb.org.uk**

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