Project title:	Developing Nutrient Management Recommendations for Selected Horticulture Crops. WP1. Hardy nursery stock literature review
Project number:	HNS 200
Project leader:	Dr Jill England, RSK ADAS
Report:	Final report, March 2022
Previous report:	n/a
Key staff:	Dr Jill England, RSK ADAS David Talbot, RSK ADAS Neil Bragg, Substrate Associates Ltd. Susie Holmes, Susie Holmes Consulting Ltd. John Adlam, Dove Associates Ltd.
Location of project:	ADAS Boxworth, Battlegate Rd, Boxworth, Cambs CB23 4NN
Industry Representative:	James Moffatt, James Coles & Sons Nurseries
Date project commenced:	1 April 2019

DISCLAIMER

While the Agriculture and Horticulture Development Board seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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.

Name: Dr Jill England

Position: Technical Director

Organisation: ADAS Horticulture

Signature   Date 17.07/2023

Report authorised by:

Name: Dr Sarah Kendall

Position: Associate Managing Director

Organisation: ADAS

Signature.   Date 17/07/23

Summary

The purpose of this review is to present new knowledge and sources of information on practical field and container grown hardy nursery stock (HNS) nutrition. This review will inform nutrient management guidance to reduce nutrients (nitrates and phosphates) in run-off through matching nutrient supply to plant need, thereby protecting the environment. For both field and container grown HNS, readily available information on fertilisers suitable for current production systems may be appropriate for inclusion in nutrient management guidance. This includes information on nutrient deficiency recognition (where trial work has provided new information) deficiency, deficiency avoidance and baseline information, e.g. standard tissue nutrient values for some key crops. This review identifies information that might be considered for inclusion in RB209 in the final stage of this project, for example nutrient and crop monitoring schedules, new crop monitoring technology and fertiliser, new application systems and new information on the release patterns for controlled release fertiliser (CRF).

The Defra Fertiliser Recommendations (RB209) are regularly updated by AHDB, with the latest update published in June 2023, but do not include a section dedicated to ornamental horticulture. The most recent version to include specific ornamental horticulture sections (MAFF, 1988) is out of date, and revised recommendations are required by HNS growers.

Ongoing grower engagement identified areas where easily accessible knowledge is lacking, and where practical recommendations are available to support current nutrient management practices and/or new approaches to optimising crop management practices.

A comprehensive literature review of nutrient management in container-grown nursery stock was carried out by Pennell *et al* (**2013**) which suggested areas for future research and development. This is referred to and supplemented where subsequent research has been conducted. Where Pennell *et al* (**2013**) published tables, e.g. for standard foliar analysis values, these have been referenced but not copied into this review as they are already accessible. Similarly, data is available in several publications, e.g. Mills and Jones (**1996**) and Aenderkerk (**1997**). There is limited new information available for field-grown nursery stock although work is underway to establish baseline information on the impact of novel fertiliser application on plant nutrient status, and the most appropriate method of assessing crop nutrient status.

CONTENTS

1. Methodology

This review combined grower engagement, literature searches and a review of AHDB and Defra publications. The AHDB publications reviewed included translated research from VuB (Vrije Universiteit Brussel) and PCS Ornamental Plant Research, Belgium. It also collates research and practices already known to the project team.

Literature searches were carried out via Web of Science (WoS) (2000 – 2023), Science Direct, ResearchGate and Alice Holt Forest Research and the AHDB. The WoS search identified an initial 2723 papers. WoS output was then reviewed and search terms refined by title and then abstract. Full papers were sourced from Science Direct, Google Scholar and ResearchGate. Search terms used for the WoS search were:

- Ornamental trees + nutrition
- Ornamental shrubs + nutrition
- Ornamental plants + biostimulants
- Herbaceous perennials + nutrition
- Herbaceous perennials
- Forest trees + Nursery
- Fruit trees

2. Grower engagement

2.1. Nutrient supply system - container crops

Grower engagement was carried out through a survey carried out at HortScience Live in 2019 and direct contact. A questionnaire (**Appendix 1**) was constructed for growers to complete and return, and as a guide for interviews. There was less interest in completing the questionnaires, however the main discussion points are presented below.

Comments were received from businesses involved in field nursery stock production (5), container production (9) and a garden centre (1). The following sections present an overview of the feedback received.

2.2. Nutrient supply system - field grown HNS

Growers generally carried out a range of practices:

- Pre-planting, growers spread green compost and some, but not all, apply farmyard manure. Others sow green manure between crops.
- Base fertiliser was applied at planting, with additional fertilisers applied if required.
- Fertilisers used by the responders:

    - Agriblend 20-10-20 slow release.
    - Straights applied as calcium nitrate, calcium magnesium.
    - Fe and Cu.
    - Ammonium nitrate
- Some growers applied single applications, supplemented later in the year, but others applied planned multiple doses of manufactured fertiliser across the season.
- For some, once crops had established no further nutrition was applied.
- Controlled release fertilisers (CRFs) were used in some field crops, notably roses, to provide nutrition through the season.

2.3. Nutrient supply system - container grown HNS

- Choice of nutrient delivery system depended on pot size to a certain extent. Large container grown or containerised trees and shrubs (e.g. in 10 L and 25 L pots) were often fertigated via drip irrigation.
- Liquid feed or CRF as a top dressing / dibble were generally applied when nutrient reserves became low. Some growers purposely applied a shorter longevity CRF (e.g. 8-9 month) and then topped up with liquid feed / CRF when required.
- Liquid feed was generally applied to cuttings and seedlings in plugs.
- Growers did group plants based on their input requirements, but priorities other than nutrition (vigour) often took precedence, e.g. temperature, light and irrigation. For protected crops, growers tended to prioritise on temperature to control plant growth and prevent plant damage.
- Growers did carry out on-site trials, particularly for plants that are susceptible to apparent nutrient problems (e.g. *Skimmia, Choisya*), focussing on such as CRF formulation and slow release Fe.

2.4. Nutrient monitoring practices

- A range of nutrient monitoring practices were undertaken, but in the main samples were submitted for laboratory analysis only if there was a problem. Others carried out routine analyses, including of substrate (ground and unground), irrigation water, and run-off EC through the year, but this appeared to be less common. ICL's AngelaWeb was also used by a number of growers.
- Leaf chlorophyll measurements appeared to be less widely used. Growers generally made a visual assessment and then applied additional fertiliser if necessary.
- In field production, some growers carried out annual soil analyses, generally pre-planting; others carried out soil analysis every 4-5 years.

2.5. Areas where knowledge or recommendations were lacking or not easily accessible

- Correct CRF rates; UK growers generally tended to follow supplier recommendations, which may be higher than necessary.
- For field grown crops there was a lack of information available for seedlings in the first and second year of growth.
- There was a lack of information for plants at the propagation stage, for example when to start applying liquid feed and what to apply to prevent plants from becoming too soft.
- Younger crops that were not yet marketable were not catered for.
- Nutrition can be difficult to manage around the change in season from late summer into the autumn as day length shortens.
- Increased understanding on the effect of N on plant hardness, and the correct balance of ammonium-N and nitrate-N to avoid soft plants.
- There was interest in new fertilisers / formulations that would either be general for all crops, or species specific. Information on using slow release N was of interest especially where peat reduced or peat free mixes were being considered and / or used.
- There was interest in using more soluble fertilisers on smaller pots as application is more consistent; there was a lack of information on rates and timings.
- There was no baseline information on optimum nutrition at species level, particularly for members of Rosaceae and salt sensitive plants.
- Lack of information for farmers wanting to establish woodland on their farms.

2.6. Knowledge exchange preferences

In 2019, growers had a preference for targeted knowledge exchange in the form of briefing notes and workshops.

3. Literature review. Field and container grown HNS

Field HNS growers tend to rely on the use of straight or compound fertilisers, with limited use of slow / CRFs in some crops. Some nurseries carry out regular soil analysis to help determine rates of fertiliser to apply, whereas other nurseries do not currently carry out regular soil analysis and apply ‘standard’ rates of fertiliser each year, regardless of soil nutrient indices. Growers rotate crops, particularly Rosacea species, typically on a minimum six year cycle to reduce the impact of replant disease, however the availability of suitable fresh land can be a problem for some nurseries. Due to the high value of field grown HNS in relation to broad acre arable crops, the cost of fertiliser is relatively low compared to the value of the crop, which can result in excessive quantities being applied.

Container HNS growers predominately rely on CRFs, which they often apply at the manufacturer recommended rates. There is an increasing interest in better management of fertiliser application to minimise the impact on the environment, including using lower CRF rates and supplementing with liquid feed as required by the crop, which also provides the flexibility to better manage the supply of individual nutrients, e.g. Phosphorus (P).

This first section of the literature review considers subject areas common to both field and container grown HNS.

3.1. Monitoring and measurement of nutrient imbalances

Integral to avoidance of nutrient deficiencies or toxicities is monitoring and understanding the crop and substrate nutrient status. The decision to apply additional liquid or foliar feed to container nursery stock is often based on grower knowledge and leaf colour. However, there is a delay before any nutrient imbalances become apparent as deficiency or toxicity symptoms; once deficiency symptoms are visible it can be too late to return the crop to an acceptable quality within the prescribed production time. A planned approach using regular on-site monitoring can prevent deficiencies and the associated loss of quality and prevent waste due to unmarketable plants. Laboratory analyses of submitted samples (e.g. substrate, tissue, and run-off) are destructive processes that can be costly and there can be a delay of up to a week between sample submission and reporting. Lower cost techniques are available that can be carried on the nursery, that can facilitate a regime of regular monitoring supported by periodic laboratory analysis.

Instantaneous analysis methods include testing growing media run-off, or leachate, using the 'pour through method' for pH and electrical conductivity (EC) using portable meters; these determine the overall availability of soluble salts to plants and the total salts in the sample respectively (**Pennell *et al.* 2013**). The simplicity of this system allows nurseries to monitor crops throughout the season, with one or two laboratory analyses of the leachate to determine the level of individual nutrients present. The ProCheck hand-held reader (www.ictinternational.com/products/procheck/procheck-handheld-reader/) fitted with a Terros 12 sensor (https://s.campbellsci.com/documents/ca/product-brochures/teros12-br.pdf provides instantaneous substrate EC / moisture readings. Nutrient charting is a process devised in Australia to provide early warning of nutrient problems, before they become chronic. The methodology promotes the use of weekly monitoring of leachate pH, EC and plant sap using nitrate strips (Merckoquant or Reflectoquant) to track monitor nutrient levels (**Stevens, 2003**).

Other relatively low cost, non-destructive methods are available, including the FieldScout GreenIndex Iphone app, which measures leaf green-ness (leaf chlorophyll level), and the atLEAF and Apogee MC-100 handheld chlorophyll meters. Of these, Adlam (**2018**) found the atLEAF+ and Apogee MC-100 chlorophyll meter and Pro-check the most useful of the equipment for use in a nursery setting to provide an immediate estimation of plant nitrogen status. However, the results were site specific so that it was not possible to compare readings between sites, and this equipment is most useful for readings taken over the course of a season to establish trends and identify reducing nitrogen status in crops. Regular readings through the season using such methods of estimating plant nutrient status can be calibrated against a dose-response curve. Identification of key high value crops or crops that are grown in large numbers to monitor through the season would be most useful when the data is collected and collated over multiple seasons and then used to inform decisions (**Adlam, 2018**).

Sap analysis

Petiole sap analysis is a test for all mobile plant nutrients that is becoming more widely available globally, however there is limited standard data available, particularly for ornamentals. Plant sap can also be used to test for sap nitrate-N alone, however, and this test is closely correlated to plant N status (**Muñoz-Huerta, 2013**). There is a range of methods to analyse sap, but the most practical for use on nurseries are the nitrate test strip (e.g. Merckoquant) or LAQUAtwin nitrate device, although these do measure sap-Nitrate, not total-N. While effective, a drawback is that while it is relatively easy to extract sap from fleshy plants, it can be difficult for subjects such as conifer needles (**Adlam, 2018, Bragg and Adlam, 2019**).

Schachtschneider *et al* (**2016**) compared rapid test methods (Table 1) to determine N (Ammonium, NH_4; Nitrate, NO_3^-; and chlorophyll, chl) and K levels in *Carpinus betulus* and newly emerged *Abies nordmanniana* needles. Testing methods were initially examined using standard sequentially diluted solutions. Then sap obtained from the subjects was examined and the results compared with analytical methods (ion chromatography and flame photometry); samples were obtained from trees grown in fertilised and non-fertilised plots. Nitrate content was determined using nitrate sticks in combination with Nitrachek and RQflex®10, although there was some underestimation in measurements for *A. nordmanniana* needles. Measurement using the nitrate LAQUAtwin electrode had inaccuracies, particularly for *A. nordmanniana* which was attributed to resin in the sap. The K^+ LAQUAtwin electrode determined the K content of both leaves and needles consistently. The ammonium content of all samples was low and unquantifiable using the test sticks alone or in combination with reflectometric methods, and there was no correlation between NH_4 measurements in the plant sap and levels in soil samples. SPAD measurements were used to compare chlorophyll measurements, but it was not possible to correlate the measurements with the two levels of fertilisation applied to the soil. A further finding was that the test sticks discoloured in response to a chemical reaction with the target chemical.

Table 1. Sap analysis testing kits and methodologies **(Schachtschneider *et al.,* 2016)**

Test kit	Method
Horiba LAQUAtwin. NO_3^- and K^+ electrodes	Ion-sensitive electrode
Quantofix	Test sticks for NH_4 and K. Interpreted visually by the user
Nitrachek	Reflectometric measurement of NO_3^-
RQflex®10	Reflectometric measurement of NH_4, NO_3^{--} and K in plant sap
SPAD	Indirect measurement of leaf chlorophyll.

Schachtschneider *et al*. (**2018**) concluded that a standard sampling procedure is needed to ensure that plant sap measurement results are consistent. They found that N and K levels were higher in the morning than in the evening, and higher in samples from older leaves than young leaves. There were large differences in N and K levels between the eleven different species of *Hydrangea* tested.

Leaf-N status

A further optical measurement that can be used as an indicator of leaf-N status is measurement of epidermal polyphenol (EPhen), recorded using a Dualex™ leaf clip meter, which can simultaneously record leaf chlorophyll. EPhen is negatively correlated with N status (EPhen level increases as N status decreases); this is counter to leaf chlorophyll which is positively correlated with nitrogen content, measured using a SPAD 502 chlorophyll meter. The Dualex™ can be used to calculate a leaf chlorophyll / EPhen ratio, the Nitrogen Balance Index (NBI) which was considered a more accurate estimate of leaf N (**Demotes-Mainard *et al*., 2008**).

A drawback of the SPAD meter is that at high N supply chlorophyll can reach saturation, preventing the detection of excessive N in plants. However, relative values of chlorophyll concentration can be obtained by using a reference N-plot within a field (this is a well fertilised plot), with the aim of eliminating the effect of stress factors (**Muñoz-Huerta, 2013**), an approach that in practice for HNS would be more suited to large areas of field trees. This approach was investigated further for woody species by Bracke *et al* (**2019**), as it is also a means of avoiding the issue of limited critical or optimum foliar nutrient data. A saturation index (SI) is calculated by dividing the sensor values into values taken from a non-N-limiting reference plot of plants that has been provided with sufficient fertilisation for healthy growth. If the SI falls below 100%, then the plant is in N-deficit as all other factors are constant; the effect of stress factors such as water stress, pests, and diseases are eliminated as the production plot and reference plot are all similarly challenged. It is important, though, to avoid over fertilisation of the reference plot, as then luxury consumption of N can result in a false deficiency indication. A threshold of 90% for action was used to determine when nutrition should be applied. This approach indicated a deficit earlier than using absolute leaf chlorophyll values.

The Smart N-Sensor is a low cost sensor that can instantaneously and non-destructively estimate whole-plant tissue N content in floriculture crops. A smartphone connected to the N-Sensor captures and transfers plant images to cloud storage, and image processing software. An algorithm has been developed that will then instantaneously estimate whole-plant tissue N content. The Smart N-Sensor can be connected to a smart phone and used as a hand-held device, or multiple sensors can be fitted to an irrigation boom to monitor larger areas (**Adhikaria *et al.*, 2020**). The system has been developed by a research group at Purdue University and has been designed for use by growers. Calibrations have been developed for *Poinsettia*, *Vinca, Salvia,* Marigold and *Zinnia*, with work underway for *Hydrangea, Hosta* and some evergreens. (**Pers. Comm. Adhikaria 2020**). While this system is geared towards bedding and pot plants rather than HNS, should it be established.

Chlorophyl fluorescence

Chlorophyll fluorescence is used as a measurement of the photosynthetic activity of plants and is widely used as an indicator of tree health; reduced photosynthetic activity is used as indicator of declining tree health. The basic principle is that light energy is absorbed by chlorophyll molecules in leaves, at which time it can be used to drive photosynthesis, dissipated as heat or re-emitted as light (chlorophyll fluorescence). These processes are in competition, so that an increase in one value will result in a decrease in the others (**Maxwell and Johnson, 2000**). These principles were used by Arborcheck, a nursery benchmark system developed for assessing tree health. Here, leaf fluorescence and leaf chlorophyll are measured non-destructively using two hand-held instruments. The results are compared with a database built up since 2009 of benchmark values determined for healthy trees grown in optimum conditions at Barcham Trees. The database contains values for over 400 trees, some identified to cultivar level, and is being expanded to include data from selected nurseries across the world. Chlorophyll fluorescence is measured using a Hansatech Instruments Plant Efficiency Analyser (PEA). This instrument illuminates a dark adapted leaf (zero photosynthetic rate) with a bright red LED, typically for 1 second, and records the chlorophyll fluorescence signal that is emitted during this illumination. When the LED is switched on, the leaf instantly (time 0) begins to fluoresce as the photosynthetic apparatus of the leaf receives light energy. The fluorescence intensity rises rapidly to a maximum level which, in a healthy tree, occurs at approximately 300–500 milliseconds. The minimum and maximum chlorophyll fluorescence are used to calculate the maximum photosynthetic efficiency of the tree according to its current state of health; a reduction in photosynthetic capacity compared with the standard value for that species indicates a tree health problem (**Arborcheck, 2020**).

3.2. Interpretation of nutrient data

While there is a move towards increased analysis of growing media, foliar and plant sap, the data for foliar and sap analysis in particular can be difficult to interpret, particularly for HNS where there is limited easily accessible standard data, and much of the data that is available is based on healthy subjects rather than providing critical nutrient thresholds.

In the UK, the European (CEN), based on 1:5 extraction (sample:distilled water) is generally used. Two analyses are available which provide 'available nutrients', and 'total available nutrients'. The latter, used in the autumn or late winter/early spring for growing media with CRF incorporated, provides values for ground samples where any remaining nutrients have been released from the CRF (**Pennell *et al.*, 2013**). A table suggesting desirable ranges of available water soluble nutrients is provided by Bragg and Holmes (**2016**), which can be used for interpretation. Analysis of unused growing media is useful to provide baseline information, allowing changes, for example in pH, to be tracked. Scoggins (**2005**) identified optimum fertiliser concentrations for 10 herbaceous perennials grown in constant liquid feed (15:7:14) at four dose rates. EC and pH were measured weekly (pour-through extraction method); plants were grouped by nutritional need and developed target EC ranges for substrate solution for the perennials tested (**Figure 1**).

Taxon	EC range ($dS \cdot m^{-1}$)
Campanula carpatica 'Blue Clips'	1.5–2.7
Astilbe chinensis 'Purpurkerze'	1.8–2.7
Heuchera ×'Mt. St. Helens'	1.9–2.9
Coreopsis verticillata 'Golden Gain'	2.1–3.1
Perovskia atriplicifolia 'Longin'	2.1–3.2
Gaura lindheimeri 'Siskiyou Pink'	2.2–3.3
Penstemon x 'Sour Grapes'	2.2–3.3
Lamium maculatum 'White Nancy'	2.7–4.1
Veronica × 'Goodness Grows'	2.8–4.2
Salvia nemerosa 'Blue Hill'	3.6–5.1

Figure 1. Suggested EC ranges for substrate solution for herbaceous perennials **(Scoggins, 2005)**

Foliar analyses are most useful for diagnosing imbalances when the results are compared with standard data, however these tend to be available only for the most widely grown species / cultivars, which makes the data difficult to interpret. Pennell *et al*. (**2013**) collated published nutrient values for a number of woody tree and shrub subjects from previous research, including Smith (**1978**)**,** Aenderkerk **(1982**), Bilderback (**undated**), Proe (**1994**), and Stirling, C. (**1996**). Further nutrient values have been published by Mills and Jones (**1996**), but again this is predominately ranges of values for healthy subjects rather than critical thresholds. Also included is a table of trace element ranges suitable for hardy ornamentals from Bunt (**1988**) and phosphate levels (**Scott, 1986**). Bragg and Holmes (**2016**) offer a range of values from a range of woody plant species, presenting the highest, average and lowest values, but suggest that nursery data for a single subject, collated over time and interpreted against images and growing media analyses would be of most use for growers. Owen (**2019**) has provided revised foliar nutrient sufficiency ranges for four *Heuchera* cultivars at different growth stages Whilst critical thresholds may not be available for a wide range of subjects, knowledge of nutrient ranges for healthy plants can help growers to optimise fertilisation practices.

For chlorophyll fluorescence an extensive database of standard data is available to members of the Arborcheck scheme (**Arborcheck, 2020**).

3.3. Monitoring regimes

A monitoring regime for container HNS is suggested by Pennell *et al.* (**2013**). Adlam (**2019**) further suggest analysis of the unused growing media (**Table 2**) with a minimum of pH and nutrient analysis in mid-summer, early autumn and late winter / early spring. For crops where nutrients are supplied by CRF, the autumn and late winter/early spring analyses should include ground and unground samples to provide an indication of nutrient reserves. Additional regular sampling of growing media EC and leaf chlorophyll can enable identification of nutrient imbalance prior to visible deficiency / toxicity symptoms developing.

For field production there is a legal requirement for analysis of pH, P, K, Mg + an assessment of N every 3-5 years under the Farming Rules for Water (**Defra, 2018**).

Table 2. Suggested analysis regime for key or high value crops **(Pennell et al. 2013, Bragg and Adlam, 2019)**

Sample type	Type of analysis	Analysis schedule
Irrigation water	Full laboratory analysis including bicarbonate (alkalinity)	Two per year, laboratory analysis
Growing medium	pH, EC and available nutrients	Unused growing media. Key crops, monthly
	pH, EC and available nutrients	Late autumn and January / February to check nutrient reserves (ground and unground samples)
Plants	Foliar analysis	When nutritional problems are suspected. Compare samples from healthy and unhealthy plants

4. Literature review. Field grown HNS

Scheduling field grown HNS can be more complex than protected crops as the speed of growth is closely linked to the prevailing weather conditions and available nutrients. Traditional methods of slowing crop growth such as undercutting are of limited use in a wet summer. Better understanding of the nutritional needs of field grown HNS species would help to prevent vigorous species from being overfed and help to control vigour whilst delivering increased profitability and environmental benefits through more sustainable fertiliser use. For less vigorous species, optimisation of nutrition through novel approaches such as targeted fertiliser placement (e.g. in bands rather than broadcast) would minimise nutrient leaching and any associated ground water contamination and further optimise crop growth with the potential to reduce production time for some species.

There are currently no standard fertiliser recommendations specifically for field grown HNS species that are readily accessible to UK nurseries. Therefore growers do not really know how much fertiliser to apply to their crops, which frequently results in high rates of fertiliser being applied, or low rates resulting in suppressed growth. Standard arable crop fertilisers can contain potassium chloride which frequently causes foliage scorch on chloride sensitive genera such as Rosacea.

The lack of recommendations for growers can lead to excessive or inappropriate fertiliser application for optimal growth of many of the species being produced; high fertiliser rates may also contravene regulations such as the Nitrogen Vulnerable Zone regulations, and contravene Catchment Sensitive Farming guidelines.

4.1. VuB fertiliser trials for field production

A series of trials comparing the growth of field trees treated with a range of mineral, mineral and organic, and partially coated fertilisers has been reported by VuB in their annual reports over several years. The fertiliser products used in these trials are collated in **Table** 3, with reporting of the individual trials in subsequent sections.

Table 3. Fertiliser product details (**Heise, 2015**; **Heise and Reimer, 2017**; **Heise, 2018**)

Product	Manufacturer	Effect
Alzon neo-N	SKW Piesteritz GmbH	Nitrogen fertiliser with nitrogen stabilisers. Conversion of urea to ammonium slowed by urease inhibitor (2-NPT) by 2 weeks; Conversion of N from ammonium to nitrate by nitrification inhibitor (MPA) by 6-10 weeks.
Agromaster 2-3 M	ICL Speciality Fertilisers	Partially coated complete fertiliser. N longevity 2-3 months.34% pf N coated with organic resin. N release dependent on soil temperature and moisture.
Blaukorn Premium	Compo Expert	Fast acting mineral fertiliser with no long term effect.
Field-Cote® CRF	Mivena B.V.	Resin coated fertiliser for field grown production. Release based on soil temperature. 4, 6 and 8 month longevity available.
Granustar® CRF Allround	Mivena B.V.	47% of the N is coated.
Multigro®	Haifa	Partially coated fertiliser. N released over 4 months at an average soil temperature of 21°C.
NovaTec® Premium	Compo Expert	Mineral, reduced-P complete fertiliser. Ammonium stabilized by nitrification inhibitor (DMPP), delaying nitrification by up to 10 weeks; timing depends on climate, weather and soil conditions.
NovaTec® Classic	Compo Expert	Granulated inorganic macronutrient fertiliser for crops with high K demand.. Nitrification inhibitor 3,4-DMPP to reduce leaching, delays transformation from ammonium to nitrate. Released over 4-10 weeks depending on soil temperature and humidity. Released on application of water.
TerraPlus N®	Compo Expert	Organic (68%) and mineral composition. N released over several weeks depending on soil temperature and moisture

4.1.1. Experiment using part-coated Field-Cote CRF products on cutting beds under film

Trials looking at part-coated long acting fertilisers (Field-Cote CRF) on cutting beds under film did not find that the products used (**Table** 4) improved plant quality, plant growth or plant grade out compared with NovaTec Classic fertiliser. It had been proposed that as the cutting beds could only receive a single application of fertiliser because of the film, the longer acting Field-Cote products could improve outcomes. However, the NovaTec Classic stabilised nitrogen fertiliser achieved similar results in terms of plant growth and quality while leaving less N residue and at a lower cost. A note was made that fertilisers used in this production system need to be worked evenly into the soil to ensure they are evenly distributed around the rooting area (i.e. not scattered) to ensure that sufficient water penetrates the planting holes, accessing the fertiliser granules so they can be activated (**Averdieck, 2014**).

Table 4. *Platanus hispanica* and *Ligustrum vulgare* 'Atrovirens' cuttings. Trial treatments and applications (**Averdieck, 2014**).

Treatments	Nutrient formula	Nutrient application (kg/ha)
Platanus hispanica		
Field-Cote CRF 4M	18-8-12 (+7)	60 kg N/ha
Field-Cote CRF 6M	18-8-12 (+7)	60 kg N/ha
NovaTec Classic	12-8-16 (+3)	60 kg N/ha
***Ligustrum vulgare* 'Atrovirens'**		
Field-Cote CRF 4M	18-8-12 (+7)	80 kg N/ha
Field-Cote CRF 6M	18-8-12 (+7)	80 kg N/ha
NovaTec Classic	12-8-16 (+3)	80 kg N/ha

4.1.2. Testing the partially coated product Granustart CRF Allround in nursery production

Growth of established trees of *Prunus laurocerasus* 'Herbergii' when treated with Granustar CRF Allround was compared with NovaTec® Premium plus Blaukorn Premium (**Table** 3), with two application timings (**Table** 5). More shoots (10 compared with 9), greater growth (plants an average 10 cm taller) and more top grade plants (62%, 80-100 cm compared with 38%) were achieved in the Granustar CRF Allround treatment than the NovaTec + Blaukorn treatment. In terms of nitrogen release into the soil, there was no benefit in using the partially coated Granustar product. More N was found at 30-60 cm deep for the Granustart treatment, indicating rapid breakdown and release; this benefited the *Prunus* (**VuB, 2015**).

Table 5. *Prunus laurocerasus* 'Herbergii' trial treatments and applications (**VuB, 2015**).

2017 trial treatments	Nutrient content	Nutrient application (kg/ha)	
		April 2015	**July 2015**
Granustar CRF Allround	17-7-16 (+5)	50 kg N/ha	50 kg N/ha
NovaTec® Premium + Blaukorn Premium	19-5-20 (+3) + 15-3-20 (+3)	50 kg N/ha	50 kg N/ha

4.1.3. Two-year comparison of long-term fertilisers in standard trees

Established standard trees of *Tilia x intermedia* 'Pallida' were trialled over two years (2016 and 2017) to compare growth when treated with TerraPlus N®, Agromaster 2-3 M, Multigro® and NovaTec®. TerraPlus N® and Agromaster 2-3 M reduced N leaching compared with Multigro® and NovaTec® Premium (**Heise and Reimer, 2017**). Growth was the same for all treatments. A single spring application of Multigro® provided sufficient N for the season.

Table 6. *Tilia x intermedia* 'Pallida' trial treatments and applications (**Heise and Reimer, 2017**).

2017 trial treatments	Nutrient content	Nutrient application (kg/ha)		Application dates
		Spring	Summer	
Multigro®	18-6-18 (+4)	130	n/a	May 2016 April 2017
Agromaster 2-3 M	19-5-20 (+4)	65	65	May and July 2016 April and June 2017
TerraPlus N®	12-4-6 (+3)	65	65	
NovaTec® Premium	19-5-20 (+3)	65	65	

4.1.4. Comparison of stabilized nitrogen fertilisers for field-grown trees

Single nutrient fertilisers tend to dominate in field production. They are less expensive than more complex formats and are more flexible as the level of each nutrient can be adjusted according to plant need. Heise (**2018**) carried out two trials (2017 and 2018) using single nutrient fertilisers Alzon neo-N, Urea) and more complex fertilisers (NovaTec® premium, Agromaster 2-3 month) (**Table 7**). The treatments (**Table 7**) had no impact on the height or growth of *Carpinus betula* or *Abies nordmaniana*, however the single nutrient fertiliser (Alzon) showed deficiencies (K and Mg) in *A. nordmaniana* and these would need to be applied separately. The 2018 trial found no differences in *Fagus sylvatica* 'Purpurea' because of the treatments, with strong new growth in all treatments. While the Agromaster and NovaTec® Premium products need a second application, the urea and Alzon neo-N treatments did not. There are nuances reported regarding the requirements of the plants used in these trials: *A. nordmaniana* has a high N demand in the spring, which could suit the Agromaster and NovaTec® Premium without a second application; *C. betula* and *F. sylvatica* have a continuous requirement through the growing season therefore a single application of Alzon neo-N may be a more practical and cost effective approach for these species.

Table 7. *Carpinus betula* (2017), *Abies nordmaniana (*2017) and *Fagus sylvatica* 'Purpureum' 2018) trial treatments and applications (**Heise, 2018**)

2017 trial treatments	Nutrient content (%)	Nutrient application (kg/ha).		No. of applications
Alzon neo-N	15-3-20	261		1
Agromaster 2-3 M	19-5-20	315		2
NovaTec® Premium	19-5-20	400		2
Urea	46 N	130		2
2018 trial treatments	**Nutrient content (%)**	**Nutrient application (kg/ha)**		
Alzon neo-N + Patentkali	15-3-20 30 K_2O, 10 MgO	260 + 198	None 335 kg/ha	
Agromaster 2-3 M + Patentkali	46 N 30 K_2O, 10 MgO	331 + 113	330 + 68	
NovaTec® Premium + Keiserite	19-5-20 25 MgO	400 + 58	400 + 58	

4.2. Growth control

Growers struggle to control the growth of certain tree species, (e.g. *Alnus*, *Betula*, and *Prunus*) resulting in plants often exceeding height specifications, particularly in the second year of production. This can add cost when handling and cold storing, and excessively large stock can be difficult to market resulting in wastage (**Talbot, 2016**). Plant growth regulators (PGRs) can help to control growth in these vigorous species to an extent but the limited research carried out has highlighted the few options available; phytotoxicity can also be a problem in some species. An improvement would be to use nutrition to control the growth of vigorous species and avoid the need to apply a pesticide (i.e. PGR) which could cause crop damage in sensitive species.

For some species growth is typically slow in field production (e.g. *Prunus laurocerasus*, *Taxus, Ilex*, *Weigela*) and as a result these crops have longer production cycles than other HNS species. This adds to production cost and results in crop management problems such as small blocks of stock remaining in the field where other crops have been lifted.

The ability to check crop nutritional status in the field during the growing season will give growers greater control over crop growth as nutritional management decisions can be made instantly. The most reliable method of determining nutritional status needs to be found; potential options are thought to include: soil electrical conductivity, leaf tissue analysis (deciduous crops at this stage) and the use of chlorophyll meters. This potentially gives growers the ability to apply the nutrients used by the crop, when they are needed in order to maximise crop growth responses. Being able to check crop nutritional status quickly and easily will also give growers the confidence to plant vigorous crops with reduced amounts of base fertiliser or in the case of very vigorous crops no base fertiliser at all, with moderated amounts of top dressing applied as necessary during the growing season.

4.3. Nutrient placement

Work has been carried out that considers nutrient placement close to the root zone, particularly for row crops e.g. transplants and field grown trees. Previous work in Scoresby Research Station, Victoria, Australia which looked at reduced root zone applications found that when applying nutrients and water to as little as 25% of the root area, the health of a tree was maintained but at reduced growth rate (**Taylor and Goubran, 1976; Frith, 1975**). Exploring the potential of band application methods could reduce N applications to comply with Nitrogen Vulnerable Zone (NVZ) maximum applications while still achieving the required crop growth.

Previous AHDB Horticulture research on nutrition has tended to focus on container production with limited carried out on field grown crops, and therefore has not addressed fertiliser placement.

4.4. Stock plant management

Stock plants are produced to provide a reliable supply of propagation material. Hewson and Hutchinson (**2014**) provides tables of N, phosphate (P_2O_5), potash (K_2O) and magnesium (Mg) requirements for field grown nursery stock (**Table 8**) and (**Table 9**) suitable for stock plant bed preparation. They advise that some plant groups are sensitive to excessive soluble fertiliser (slow growing conifers, ericaceous spp. and liners). For these crops it is better to apply N once established (**Table 8**). Ammonium nitrate (e.g. Nitram) is more suited to ericaceous and calcifuge subjects than ammonium nitrate lime fertilisers (e.g. Nitrochalk), advising that soil pH can be reduced further by using ammonium sulphate. These top dressing rates should be used to maintain stock bed nutrition, with soil analyses undertaken every three years to confirm the nutrient status of the soil, particularly as excess N will reduced rooting performance.

Table 8. Nitrogen rates for field grown nursery stock (**Hewson and Hutchinson, 2014**)

Species	Base dressing (kg.ha N)	Top dressing (kgha N)
Ericaceous, calcifuge and slow growing spp.	0-50	0-50
Medium and quick growing spp.	50-150	50-150

Table 9. Phosphate (P_2O_5), potash (K_2O) and magnesium (Mg) requirements for field grown nursery stock by soil analysis. Figures in bold should be used in absence of soil analysis data. If a heavy dressing of farmyard manure is applied before planting, the fertiliser can be reduced by 20 kg/ha phosphate, 40 kg/ha potash and 8 kg/ha magnesium per 10 tonnes manure. A minimum of 50 kg/ha phosphate and potash as fertiliser should always be applied where the soil index is 0 or 1. *Use magnesian limestone for calcicole areas and kieserite for ericaceous , calcifuge and conifer areas. ** For top dressing, where K index is at the lower end of Index 2, apply 50 kg/ha. (**Hewson and Hutchinson, 2014**)

Soil P, K or Mg Index	Before planting			Top dressing		
	Phosphate	Potash	Mg*	Phosphate	Potash	Mg
	Kg/ha			Kg/ha		
0	100	200	75	50	100	25
1	75	150	50	25	50	Nil
2	**50**	**100**	25	**Nil**	**25****	**Nil**
3	25	50	**Nil**	Nil	Nil	Nil
Over 3	Nil	Nil	Nil	Nil	Nil	Nil

4.5. Literature review. Container grown HNS

Most nursery stock growers tend to use a base fertiliser with CRF, usually added by the growing media manufacturer, to provide sufficient nutrition for the production phase. Pennell *et al*. (**2013**) raised potential environmental and quality issues concerning total reliance on CRF. Temperature extremes due to changing weather patterns can give rise to nutrient release when plants are unable to utilise it, particularly in plants grown under protection, and this increases the potential for nutrient leaching or plant damage due to the build-up of nutrients in the substrate. Increasing attention is being given to environmental pollution due to the excessive loss of nutrients under specific weather conditions, including point sourced pollution from plant nurseries.

Whilst previous work has been carried out that investigated the use of CRFs under protection (**Scott *et al*., 1993**), formulations and coatings have since been further developed by the manufacturers.

Early work to evaluate the use of computer simulation models that generally gave good predictions did not allow for leaching of nutrients and ultimately were not adopted in commercial practice or allow for leaching of nutrients (**Scott, 1996**). There is currently no standardised method to reliably determine the release rate from CRFs – nutrient release is controlled by diffusion, swelling, erosion or a combination, therefore any modelling approach should match the materials used and the release mechanism. The focus of much of the current CRF development work is on using environmentally friendly materials that can better control release rate (**Lawrencia *et al.*, 2021**). Other publications have contributed methodologies for sampling and analysis interpretation by growers (**Bragg and Holmes, 2016**) and data on nutrient leaching (**Adlam, 2018**).

4.6. Nutrient leaching

Previous work has been carried out that has either focused on nutrient leaching (**Maher *et al.*, 2002**; **Adlam, 2009**; and **Adlam, 2018**), or from which leachability can be inferred (**Briercliffe *et al.*, 2000**). While Harris *et al.* (**1997**) found nitrate-N levels in run-off from container beds exceeding 200 mg/L, and phosphorus exceeding 20 mg/L, Adlam **(2009**) detected total nitrogen below 50 mg/L (the current NVZ drinking water limit), but phosphorus levels above the acceptable level in rivers (>0.1 mg/L). Previously, work by Maher *et al.* (**2002**) reinforced the need to link CRF nutrient supply with plant need, given that for *Thuja plicata* there was little benefit in increasing CRF above 4 g/L, while *Lonicera pileata* responded to rates up to 8 g/L. With nutrient losses increasing with CRF dose rate (14 Kg/ha at 4 g/L CRF; 18 Kg/ha at 6 g/L CRF; and 40 Kg/ha at 8 g/L CRF), this was particularly important in outdoor crops where nutrient loss is closely linked to rainfall. Adlam (**2018**) found that nitrate-N leaching reduced over the season, but also that trimming plants causes a spike in nitrate-N in run-off water. Adlam (**2018**) concluded that plants should be categorised into high, medium and low feed groups to match nutrient application to plant need and reduce run-off. *Buddleija* and *Tradescantia* were categorised as high feeders, while *Viburnum* was a medium feeder.

4.7. Fertiliser release patterns (CRF and base fertiliser)

There is a lack of currently accessible independent information which allows comparison of the technical aspects (e.g. nutrient release patterns, environmental conditions under which nutrients are released) of the various CRF brands and formulations (coating and longevity) on the market. While CRF manufacturers will have detailed information on the nutrient release patterns of their products, there is little peer reviewed scientifically robust data to draw upon. CRFs are sensitive to both substrate moisture and temperature; although excess water does not influence nutrient release, it is positively correlated with substrate temperature and therefore sensitive to prevailing environmental conditions. For non-urea containing CRFs, nutrient release in the field can be determined effectively (and non-destructively) by measurement of electrical conductivity (EC) using the ‘pour through’ method (**Hojjatie and Carney, 2014**).

Release patterns are controlled by the prill coating technology. Nutricote products have a resin coating with a chemical release agent that determines how porous the coating is and the amount of nutrients that are released; it is only the quantity of the release agent that is altered between formulations. Basacote has an impermeable elastic polymer coating that controls water ingress, with the thickness of the coating determining how quickly water enters the granule; nutrient release is governed by ambient temperature, the mechanism provided by CAR (climate adapted release) technology. Osmocote products are now in their fourth generation: Osmocote (1st Gen.), Osmocote Pro (2nd Gen.), Osmocote Exact (3rd Gen.) and Osmocote Exact DCT (Dual Coat Technology, 4th Gen). For the DCT formulations, e.g. Osmocote Exact Hi-End, release is delayed until 2-3 months after application when plants are in the second growth phase.

Independent laboratory analysis to characterise nutrient release patterns of base fertilisers and CRFs has recently been undertaken using the EN13266 method described by Terlingen et al. (**2016**), which measures nutrient release in water at a set temperature over time. The analysis has been completed on a range of products and formulations (coating and longevity) currently marketed by a number of manufacturers (Osmocote, ICL; Nutricote, Arysta Life Science; Horticote, PG Horticulture; Basacote, Compo; Plantacote, Yara), at 25˚C and 50˚C, with 2 g CRF per 100ml distilled water (EC -3 µs/cm) (**Pers. Comm**. **Ann Mc Cann, Bulrush Horticulture**). The Nutricote products were less affected by temperature (**Figure 2**) showing little difference in their release pattern at either temperature; however, temperature had a greater effect on the Osmocote Exact and Basacote at 50˚C, both of which had high initial nutrient release. Considering that the two Osmocote products had the same 8-9 month longevity, the release curves were very different, nutrient release by the Osmocote Pro did not have the same high initial release as the other products. In **Figure 3**, it can be seen that the DCT formulation of the two Osmocote Exact products does result in lower initial nutrient release, with greatest initial release seen in the shorter longevity products (Osmocote Exact 5-6M and Osmocote Hi-K 5-6M). High initial nutrient release was found in some of the Nutricote products (**Figure 4**), particularly the mini (70D and 140D) products, which are designed for use in small pack cells. Several formulations of PG Cote were tested (**Figure 5**). Comparing those with the same NPK ratio, those with shorter longevities released more nutrient over the duration of the test, with higher initial nutrient release from the 6-month formulation.

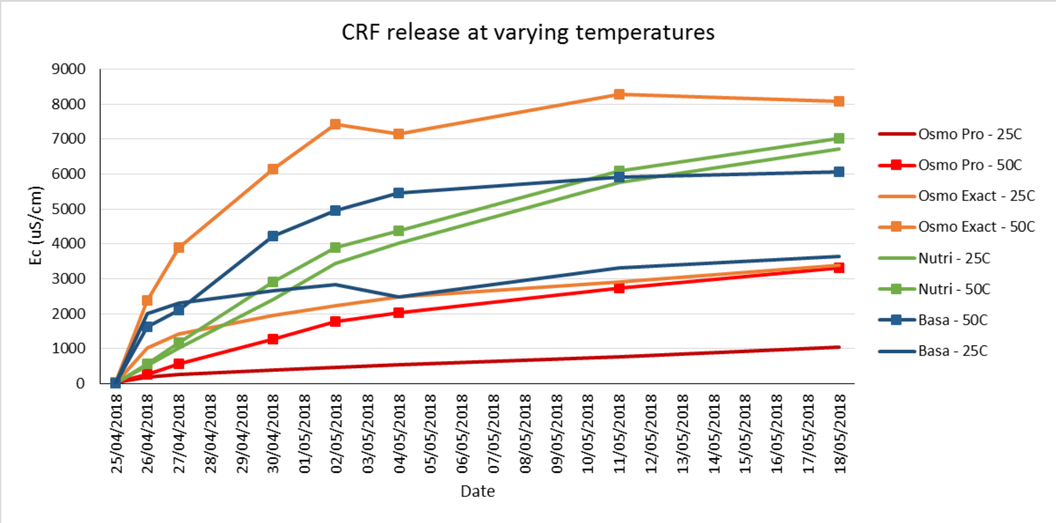

Figure 2. CRF release patterns at 25˚C and 50˚C, following EN13266 method (**Terlingen et al., 2016**). Formulations tested were: Osmocote Pro 8-9M Osmocote Exact Protect 8-9M, Nutricote 140D and Basacote 9M.

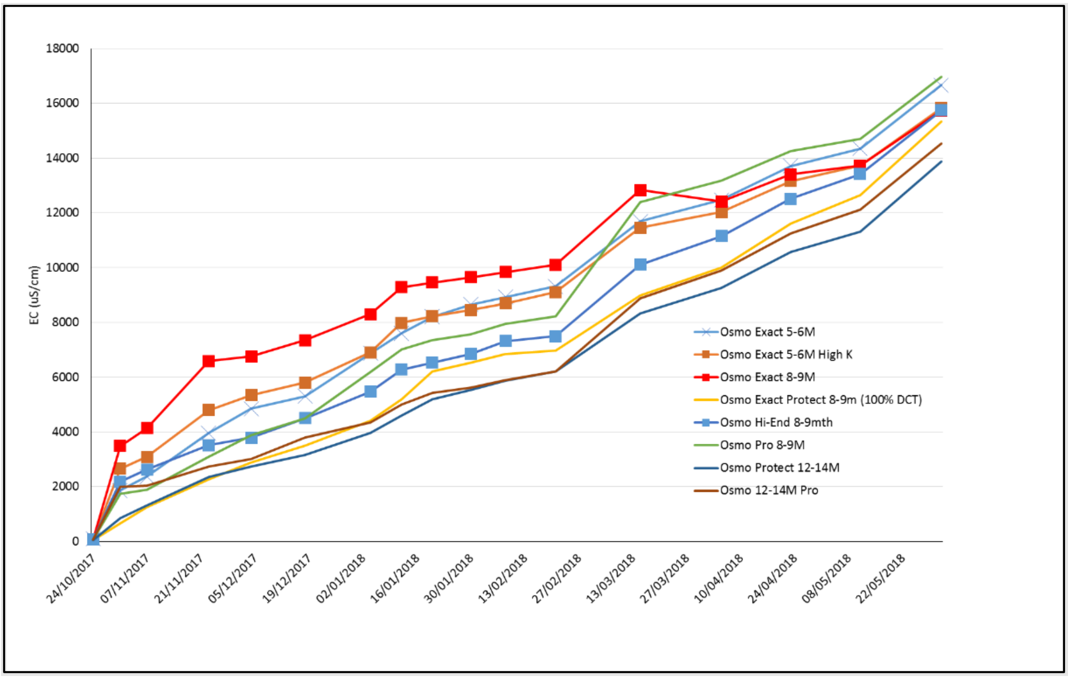

Figure 3. Osmocote CRF release patterns at 25˚C following EN13266 method (**Terlingen et al., 2016**)

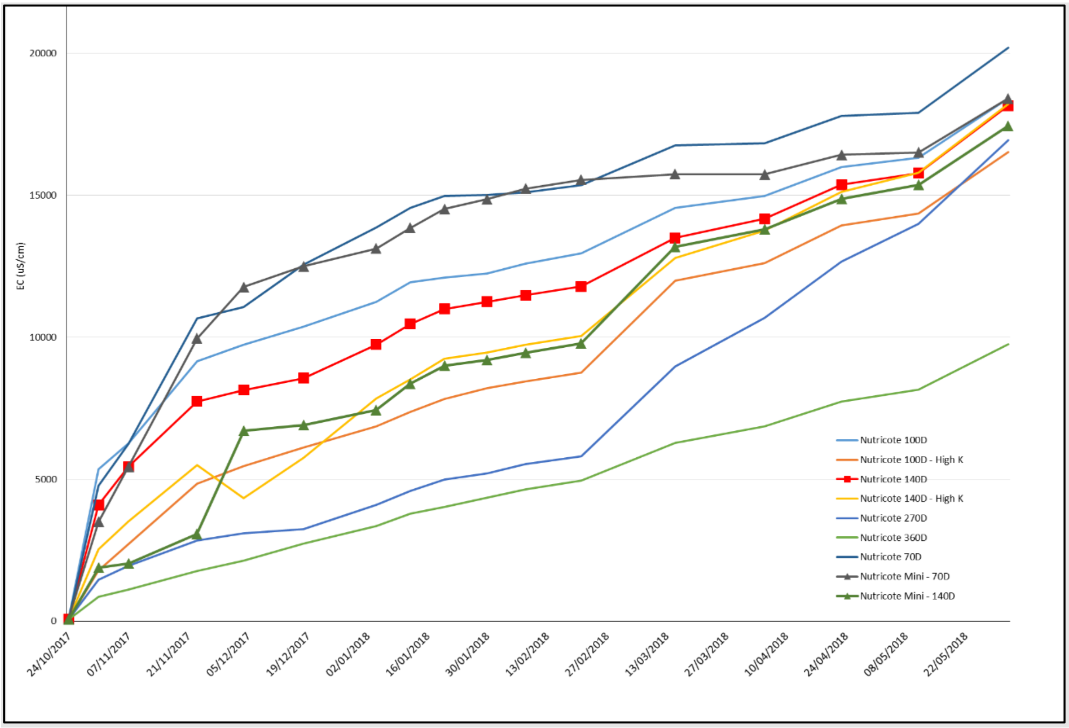

Figure 4. Nutricote CRF release patterns at 25˚C following EN13266 method (**Terlingen et al., 2016**)

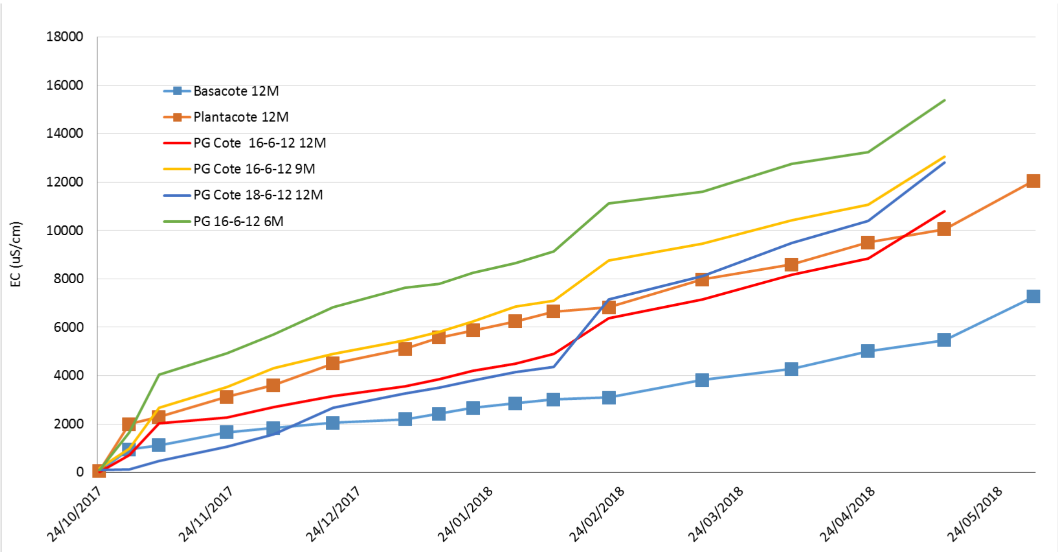

Figure 5. Various products, CRF release patterns at 25˚C following EN13266 method (**Terlingen et al., 2016**)

Alternatively, Pennell, *et al*., (**2013**) suggests the implementation of a day degree/thermal time model would improve understanding of the conditions when CRF nutrient release occurs, and enable prediction of both nutrient release and the requirement for supplementary feeds.

4.8. Comparison of CRF fertilisation with liquid feed

Kleiber *et al.* (**2019**) found that fertigation improved growth of pot grown *Berberis* × *ottawensis* var. Superba, and *Thuja occidentalis* var. Smaragd) (two dose rates) compared with CRF (Osmocote Exact Standard 5-6M), but not *Juniperus* × *pfitzeriana* var. Mordigan Gold. *Berberis* response was improved by the higher rate of fertigation, while both the higher and lower rates appeared suitable for *Thuja*, with an acknowledgement that further work would be needed to optimise the chemical balance of the feed. This work provided tentative leaf tissue analysis values for the *Berberis* and *Thuja* (**Table 10**).

Table 10. Tentative guideline leaf tissue analysis values for *Berberis* × *ottawensis* var. Superba and *Thuja occidentalis* var. Smaragd'

Species	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**
	g/kg d.m	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**	**g/kg d.m**
Berberis × ottawensis var. Superba	9.30	3.75	13.10	10.05	1.55	41.05	29.40	13.95	3.58
Thuja occidentalis var. Smaragd'	13.55	2.55	13.10	17.40	1.75	77.35	188.00	59.40	4.36

4.9. Recommendations for CRF / liquid feed combinations

AHDB funded research (**England *et al.* 2023**) to develop recommendations for inclusion in RB209 looked at combining lower CRF rates and topping up with liquid feed to produce marketable HNS species (*Prunus lusitanica* 'Myrtifolia', *Spiraea arguta* and *Geranium x cantabrigiense* 'Westray' and *Tradescantia pallida* 'Purple Sabre'). Various liquid feed regimes were tested with regular crop monitoring (EC, chlorophyll, growing media and tissue analysis) to determine plant uptake and if nutrient applications were excessive. A number of CRF / liquid feed combinations proved successful over two growing seasons and have been developed into the recommendations below:

Recommendation 1 – Low CRF, low weekly liquid feed

CRF: 12-14 month, 1.5 g/L mixed or dibbled at potting

Liquid feed applied once per week at 0.5%:

- 10:52:10 (N:P:K) for four weeks from transplant
- 3:1:3 (N:P:K) from 5 weeks after transplant

Suitable for Prunus lusitanica 'Myrtifolia', Spiraea arguta and Geranium x cantabrigiense 'Westray' were produced under this regime.

This option provides less nutrients than Recommendations 2 and 3, and requires less labour input than Recommendation 3.

Recommendation 2 – Low CRF, higher weekly liquid feed

CRF: 12-14 month, 1.5 g/L mixed or dibbled at potting

Liquid feed applied once per week at 1.0%:

- 10:52:10 (N:P:K) for four weeks from transplant
- 3:1:3 (N:P:K) from 5 weeks after transplant

This option uses less liquid feed than Recommendation 3, and the lower nutrient content may help to restrict the growth of vigorous species such as Tradescantia and there is less risk of excess nutrients being applied.

Suitable for Spiraea arguta, Geranium x cantabrigiense 'Westray' and Tradescantia pallida 'Purple Sabre'.

Recommendation 3 – Low CRF, low liquid feed at every irrigation

CRF: 12-14 month, 1.5 g/L mixed or dibbled at potting

Liquid feed: applied at each irrigation at 0.5%

- 10:52:10 (N:P:K) for four weeks from transplant
- 3:1:3 (N:P:K) from 5 weeks after transplant

The liquid feed rate should be adjusted to meet the needs of the crop to prevent excessive application and nutrient loss in run-off water. Lower feed rates could be used to manage growth of vigorous species such as Tradescantia pallida 'Purple Sabre'. However, this option requires more labour input to produce plants of similar quality.

Suitable for Tradescantia pallida 'Purple Sabre'.

To select the most effective recommendation for your crop you will need to consider your plant nutrient needs and monitor nutrient supply

4.10. Nutrition of container grown heathers

AHDB funded research (**Monaghan, 2002**) identified suitable CRF rates for heathers grown either outdoors or under protection. 1.5 kg/m^3 of a medium to long term CRF (e.g. Vitacote, Multicote 8, Osmocote Plus (12-14) Autumn or Osmocote Exact Standard was determined to be a suitable rate.

5. Correcting nutrient imbalance

5.1. Tip dieback in *Ligustrum vulgare* 'Atrovirens'

Symptoms of tip dieback in field-grown *Ligustrum vulgare* 'Atrovirens' are: dieback of the buds around the tip, slight twisting of the newest leaves at the tips, claret to violet discolouration starting with the leaves towards the shoot tip and leaf abscission (**Figure 6**). The cause, often considered to be due to either copper (Cu) or boron (B) deficiency, was explored through foliar or granulated applications of formulations containing Cu, B, Cu and B and calcium chelate. The most effective treatments contained B (**Table 11, Trial 1**) while there was only a small effect achieved by treatments containing Cu. Treatments containing B were more effective whether applied as granules or as a foliar feed. The trial was repeated with plants that were already affected receiving treatments containing B at a higher application rate (**Table 11, Trial 2**). The treatments were not effective as the plants were too severely affected, but the treatments did not cause crop damage (**Heise, 2016**).

Table 11. *Ligustrum* dieback: fertiliser product details and effects (**Heise, 2016**). Plants in trial 1 were unaffected before treatment, and affected before treatment in trial 2. Treatments with greatest effect highlighted red

Trial 1			
Product	**Nutrient**	**Dose**	**Effect**
Exello-Kupfer spezial	5.0 % Cu	100 kg/ha	No significant effect
Excello-331 spezial	1.0% B, 0.2% Cu	200 kg/ha	Reduced symptoms
Mivena Hort-mix	0.6% B, 0.6% Cu	334 kg/ha	No significant effect
Haifa Coated Bor 12 M	12% B	100 kg/ha	Most effective
Folicin-Bor Plus fluid	140 g/L B	4 x 1.5 L/ha	Reduced symptoms
Folicin-Cu fluid	117 g/L Cu	4 x 2.0 L/ha	No significant effect
Folicin-Bor Plus fluid + Folicin-Cu fluid	140 g/L B 117 g/L Cu	4 x 1.5 L/ha 4 x 2.0 L/ha	No significant effect
Wuxal Boron	96 g/L B	4 x 2.0 L/ha	Most effective
Stefes Bor	150 g/L B	4 x 1.5 L/ha	Most effective
Solubor DF	17.5% B	4 x 1.5 kg/ha	Reduced symptoms
Calcium chelate	14% Ca	4 x 2.5 kg/ha	No significant effect
Trial 2			
Product	**Nutrient**	**Dose**	**Effect**
Folicin-Bor Plus fluid	140 g/L B	3 x 2.0 L/ha	No effect. No crop damage at these high rates
Wuxal Boron	96 g/L B	3 x 2.0 L/ha	
Profi Bor 150	150 g/L B	3 x 2.0 L/ha	

Figure 6. *Ligustrum* tip dieback: Twisting of the newest leaves (left), violet leaf discolouration (centre) and start of shoot tip dieback (right) Images extracted **from Heise (2016**)

5.2. Tip burn in *Cordyline* and *Phormium* and *Cordyline* yellow leaf spot

Tip burn in *Cordyline* and *Phormium* was considered to be due to nutrient imbalance, potentially Ca, B or K deficiency; or B, or Fl toxicity; symptoms are leaf margin and tip browning. The cause of *Cordyline* yellow leaf spot syndrome was unknown; symptoms are unsightly yellow leaf spots, initially small raised pustules, apparently water soaked, that sometimes turn necrotic. Nutrient trials saw tip burn in *Cordyline* significantly reduced by weekly applications of calcium nitrate (foliar feed, 1520 mg/L; and liquid feed, 150 mg/L) and potassium nitrate (liquid feed, 200 mg/L) (**Table 12**). Symptoms of *Cordyline* yellow leaf spot syndrome were also reduced by the same treatments (**England, 2013**).

Table 12. Tip burn in *Cordyline* and *Phormium*; yellow leaf spot in *Cordyline.* Effective treatments (**England, 2013**)

Condition	Product	Treatment
Tip burn *Cordyline* and *Phormium*	Calcium nitrate	Foliar feed, 1520 mg/L
	Calcium nitrate	Liquid feed, 150 mg/L
	Potassium nitrate	Liquid feed, 200 mg/L
Yellow leaf spot *Cordyline*	Calcium nitrate	Foliar feed, 1520 mg/L
	Calcium nitrate	Liquid feed, 150 mg/L
	Potassium nitrate	Liquid feed, 200 mg/L

5.3. Improving the colour of conifers in autumn

Field grown conifers often suffer from severe yellowing during the autumn and winter, predominately in light sandy soils, with pines most commonly affected, according to Averdieck (**2014**). Applications of K and Mg are usually made to correct this but are not always successful. Fertiliser trials compared applications of Mg and K fertilisers to *Pinus strobus* and

Pinus mugo. Fertilisers for the trial were selected to examine the influence of Fe, S, and N as well as K and Mg on plant colour (**Table 13**). Yellowing did occur to the plants in the trials. The most effective treatments contained N, with the best results obtained using Ferro Top which also contained Fe.

Table 13. Improving the colour of conifers in the autumn. Trial details. Red text = the treatment with the greatest effect **(Averdieck, 2014)**

Product	Formulation	Dose rate	Outcome
Patentkali	30% K2O, 1-% MgO, 17% S	500 kg/ha	Slight improvement
ESTA Kieserit granules	25% MgO, 20% S	500 kg/ha	Slight improvement
Bittersalz ($MgSO_4$)	16% MgO, 13% S	800 kg/ha	Slight improvement
CalMag coated fertiliser*	9-0-0 + 16% CaO + 9% MgO	500 kg/ha	Good effect
Ferrogranul 20	20% ferrous II sulphate	250 kg/ha	Slight improvement
Ferro Top	6-0-12-6 + 18% S + 8% Fe	500 kg/ha	Most effective
Sferosol	87% S	500 kg/ha	Little effect
Blaukorn Classic	12-8-16-3	350 kg/ha	Good effect
Agromaster 2-3M part coated fertiliser	9-5-20-4	250 kg/ha	Good effect

*Applied to Pinus strobus only

6. Biostimulants

There are multiple definitions of biostimulants. The Health and Safety Executive defines a 'plant biostimulant' as 'a product that stimulates plant nutrition processes independently of the product's nutrient content', and this applies when 'the sole aim is improving the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency, tolerance to abiotic stress, quality traits and availability of confined nutrients in soil or rhizosphere' (**Health and Safety Executive, 2023**). The use of biostimulants appears to be becoming more commonplace as growers strive to find sustainable products to use in place of mineral nutrient products.

A recent review of evidence for the safe and effective use of biostimulants (Enhanced Efficiency Fertilisers, EEF) looked at their use in arable and field-grown horticultural crops (relevant to the UK). It classified biostimulants into 11 categories: seaweed extracts, humic substances (HS), phosphite and other inorganic salts, chitin and chitosan derivatives, antitranspirants, protein hydrolysates and free amino acids, non-essential chemical elements, complex organic materials, plant growth promoting bacteria (PGPB), arbuscular mycorrhizal fungi, non-pathogenic fungi and protozoa and nematodes. The study recognised that this is a relative new but fast growing area of research, but the conclusions were mixed, with a variable amount of evidence available for the various product groups. There was evidence for a positive effect on plant growth or yield but less for improved nutrient uptake and plant quality, minimal evidence for improved nutrient use efficiency and tolerance to abiotic stress. There was a lack of evidence on either the economic benefits of applying biostimulants or human and environmental safety (**Storer and Berdeni, 2022**).

Studies on the use of biostimulants in HNS production are limited; most research has been carried out on arable, fruit and vegetable crops, which define benefits such as yield and sugar content rather than the plant height or quality parameters used to define marketability for ornamental subjects.

6.1. Humate products

Granular and liquid humate products (marketed as biostimulants) did not increase the early establishment (root length, height or stem diameter) of balled and burlapped *Acer rubrum* (**Kelting *et al.*,1998a)**, although there was some increase in sap flow suggesting increased water uptake. Further work looking at establishment of *Acer rubrum* and *Crataegus phaenopyrum* when humates (granular applied at two rates, and liquid humates) did not increase the height, stem diameter, shoot dry mass or root length. However, application of granular humate at 200 g/tree did increase total root length compared with application at 100 g/tree **(Kelting *et al.*, 1998b**).

6.2. Amino acids

Ozyhar *et al.* (**2019**) reported a positive effect of an amino acid-based animal-derived protein hydrolysate biostimulant (Siapton® by Isagro) on the growth of containerised *Eucalyptus globulus* Labill seedlings when applied post-transplant into 60 cell plug trays as foliar (2.5 ml/L and 5.0 ml/L) and drench (10 ml/L and 20 ml/L) applications in a trial carried out in Italy. Treatments were applied weekly for five weeks before subsequent transplant into 10 L pots. Significant increases in the dry weight of above ground biomass and leaves were recorded where foliar applications at 2.5 ml/L were made (but no significant effect on height, collar diameter or below ground biomass).

Pennell *et al.* (**2013**) highlighted that further work would help with understanding the role of mycorrhizal fungi in P nutrition of container HNS production.

Biostimulant products are increasingly being considered as a low carbon option to mineral fertilisers however there appears to be a lack of evidence on increased growth because of improved nutrient uptake or nitrogen use efficiency, and tolerance to abiotic stress. There are many businesses producing biostimulants products for which they provide information for growers, but this is a relatively new area of research and there is a lack of independent research to date confirming their efficacy and mode of action, particularly related to HNS.

There is a lack of published data on the nutrient demands of the large number of species and cultivars that growers produce both in field and container production. While some information may be built up within nurseries it isn't easily accessible across all growers and often the fertiliser rates used are too high, leading to unnecessary costs and potential pollution. With advice to carry out more nutrient monitoring, particularly foliar analysis, growers need more advice on interpretation for key / priority crops, but standard data is not available for all species / cultivars. While some tables provide critical thresholds, these are limited and some publications are rare and expensive (e.g. **Mills and Jones, 1996**). There are data that could be drawn from research papers and used as guidance, which could be updated as more information becomes available, but these are not easily accessible, and growers would benefit from a central digitally available reference database.

The container trials carried out under HNS 200 have produced recommendations for the reduction of CRF applications, topping up nutrition with liquid feed as required. Growers rely on fertiliser manufacturer recommendations for the rate to use, but this work indicated that CRF rates could be reduced substantially without a negative effect on plant quality and could also help to control growth of vigorous plants. More work could identify if this is a general trend across different manufacturers and products and increase grower confidence in adjusting CRF rates without impacting plant quality.

6.3. Soluble bioorganic substances (SBS)

There is a need for research on how best to deploy these products in ornamental plant production for maximum benefits, and to critically evaluate their benefits.

7. Gap analysis

There are a number of areas where further work is needed – and this includes areas previously highlighted by Pennell et al. (2013) for container HNS.

Much of the work relating to container production relates to peat based growing media, with a lack of recommendations for peat free substrates. Nutrition will need to be adjusted to account for different substrates, particularly where nitrogen immobilisation is an issue e.g. wood fibre and bark.

Pennell et al. highlighted that further work would help with understanding the role mycorrhizal fungi in P nutrition of container HNS production.

Growers struggle to control the growth of vigorous tree species, particularly when growing to specific height specifications. Greater knowledge of around effective growth control through manipulating fertiliser applications would help growers contain costs through maintaining planned production cycles and improved uniformity of growth.

Biostimulant products are increasingly being considered as a low carbon option to mineral fertilisers, however there appears to be a lack of evidence on increased growth because of improved nutrient uptake or nitrogen use efficiency, and tolerance to abiotic stress. There are a large number of businesses producing biostimulants products for which they provide information for growers, but this is a relatively new area of research and there is a lack of independent research to date confirming their efficacy and mode of action, particularly related to HNS.

There is a lack of published data on the nutrient demands of the large number of species and cultivars that growers produce both in field and container production. While some information may be built up within nurseries it isn't easily accessible across all growers and often the fertiliser rates used are too high, leading to unnecessary costs and potential pollution. With advice to carry out more nutrient monitoring, particularly foliar analysis, growers need more advice on interpretation for key / priority crops, but standard data is not available for all species / cultivars. While some tables provide critical thresholds, these are limited and some publications are rare and expensive (e.g. **Mills and Jones, 1996**). There are data that could be drawn from research papers and used as guidance, which could be updated as more information becomes available, but these are not easily accessible and growers would benefit from a central digitally available reference database.

Growers may also benefit from more encouragement through knowledge exchange to monitor their crops, in terms of techniques and equipment and data interpretation to increase uptake. This will enable more accurate nutrient application which would help to mitigate the risk of pollution because of excess fertiliser application.

The container trials carried out under HNS 200 (**England *et al.* 2023**) have produced recommendations for the reduction of CRF applications, topping up nutrition with liquid feed as required (**4.9**). This work indicated that CRF rates may be reduced without a negative effect on plant quality, and could also help to control growth of vigorous plants. However, the trials were not designed to provide recommendations for specific CRF rates; manufacturers have designed products using their own nutrient release technology and to their own specifications. Growers then rely on fertiliser manufacturer recommendations for the rate to use. More work looking at applying lower CRF rates and topping up with liquid feeds, guided by associated crop monitoring, could increase grower confidence in adjusting CRF rates without impacting plant quality.

8. Conclusions

There appear to be some key areas where more work is required:

- Provision of baseline information on plant nutrient demand to species / cultivar level, including the correct CRF rates (which may be lower than supplier recommendations) and through the collation and regular update of foliar analysis data
- Nutrition recommendations linked to substrate material (wood fibre, bark etc).
- Further work on biostimulants to provide evidence of the effect on HNS subjects and the mode of action to provide clear recommendations for growers, particularly in light of the increasing number of products on the market.

9. Further guidance on fertiliser use

AHDB Factsheet 05/19 Nutrition of container-grown hardy nursery stock

AHDB Factsheet 15/06 Water quality for the irrigation of ornamental crops

AHDB Factsheet10/16 Sampling methodologies and analysis interpretation for growers of hardy nursery stock

Factsheet 14/04 Hardy nursery stock – management of stock plants

Schoeters (**2021**) provides general guidance on nutrients and fertiliser use for field grown ornamentals including practical aspects of developing and implementing a fertiliser plan.

Majsztrik and Owen (**2020**) provides guidance on irrigation water, nutrients and fertilisers for field and protected ornamental production.

10. References

Adhikaria, R., Cheng Li, C., Kalbaugh, K., Nemalia. (**2020**). A low-cost smartphone controlled sensor based on image analysis for estimating whole-plant tissue nitrogen (N) content in floriculture crops. *Computers and Electronics in Agriculture*. Volume 169, 105173. Retrieved 1.07.20 from: https://www.sciencedirect.com/science/article/pii/S0168169919322884#!.

Adlam, J. and Bragg, N. (**2018**) Nutrient management in hardy nursery stock (NutrHONS). AHDB project HNS 193.

Adlam, J., Rayment, A., (**2009**) Survey of nutrient run-off from container beds of hardy nursery stock nurseries in England. HDC project HNS 158.

Aendekerk, Theo (**1997**) Fertilization guide for nursery crops. Boomteeltpraktijkonderzoek, Boskoop. The Netherlands.

AHDB (**2020**) Nutrient Management Guide (RB209). Available at: https://ahdb.org.uk/nutrient-management-guide-rb209. Accessed 18 June 2020.

Arborcheck. (**2020**) Tree vitality monitoring & stress detection. Hansatech Instruments Ltd. Retrieved 01.07.20 from: http://www.arborcheck.com/.

Averdieck, H. (**2014**) Experiment to improve the colour of conifers in autumn in *Annual Report 2014*. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Averdieck, H., and Wrede, A. (**2014**) Experiment using part-coated Field-Cote CRF products for cutting beds under film in *Annual Report 2014*. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Bilderback, T. (**undated**). Plant tissue parameters in woody ornamental crop production. North Carolina State University. Retrieved 1 July 2020 from: https://nurserycrops.ces.ncsu.edu/wp-content/uploads/2017/11/Nutrition-fertility-substrates-Bilderback.pdf?fwd=no.

Bracke, J. Elsen, A. Adriaenssens, S. Schoeters, L. Vandendriessche, H. and Van Labeke, M-C. (**2019**) Application of proximal optical sensors to fine-tune nitrogen fertilization: opportunities for woody ornamentals. *Agronomy*, 9, 408.

Bragg, N. and Adlam, J. (**2019**) Nutrition of container-grown hardy nursery stock. AHDB Factsheet 05/19 (revision of 05/05).

Bragg, N. and Holmes, S. (**2016**) Sampling methodologies and analysis interpretation for growers of hardy nursery stock. AHDB Factsheet 10/16.

Bragg, N.C. and Fuller, A.K. (**1997**). Cultural control of plant growth – a fresh look. Acta Hortic. 450, 535-544

Bragg, Neil (**1998**) Growing media. Grower handbook No. 1. Grower Books. Nexus Media Ltd. Kent.

Briercliffe, T., Bragg, N., Coutts, S., Kitchener, H., Jevans, A., Pettitt, T and Clarke, I. (**2000**) Protected ornamentals: the efficiency of water use in different production systems. HDC project PC 166.

Bunt, A. C. (**1988**) Media and mixes for container grown plants. Unwin Hyman. London.

Compo-Expert. (**2020**). Controlled release fertilizer. Basacote®. For substrate mixtures, horticulture, tree nurseries and plant hole fertilization. Retrieved 06.07.20 from: https://www.compo-expert.com/sites/default/files/2020-01/Folder_Basacote_EN_2018.pdf.

Conesa, María R., Pedro J. Espinosa, Diego Pallarés, and Alejandro Pérez-Pastor. (**2020**). Influence of plant biostimulant as technique to harden citrus nursery plants before transplanting to the field. *Sustainability* 12 (15), 6190. Retrieved 30.05.2023 from https://doi.org/10.3390/su12156190.

Da Silva, M. A., Cavalcante, I. H. L., Mudo, L. E. D., de Paiva Neto, V. B., Amariz, R. A., da Cunha, J. G. (**2020**). Biostimulant alleviates abiotic stress of mango grown in semiarid environment. Articles • *Rev. bras. eng. agríc. ambient.* 24 (7). Retrieved 30.05.2023 from https://doi.org/10.1590/1807-1929/agriambi.v24n7p457-464

Defra (**2018**) Rules for farmers and land managers to prevent water pollution. Retrieved 30.05.2023 from https://www.gov.uk/guidance/rules-for-farmers-and-land-managers-to-prevent-water-pollution.

Demotes-Mainard, S. Boumaza, R. Meyer, S. Cerovic, Z. G. (**2008**) Indicators of nitrogen status for ornamental woody plants based on optical measurements of leaf epidermal polyphenol and chlorophyll contents. Scientia Horticulturae. Volume 115, Issue 4, Pages 377-38.

England, J. (**2014**) *Cordyline* and *Phormium*: investigation of causes of tip burn and yellow leaf spot syndrome. HNS 171a. AHDB. Retrieved 22.06.2023 from https://projectbluearchive.blob.core.windows.net/media/Default/Research%20Papers/Horticulture/3.pdf

Frith, G. J. T. (**1975**) Nitrogen uptake by apple seedlings as affected by light, and nutrient stress in part of the root system. Scoresby Horticultural Research Station, Ferntree Gully, Victoria 3156, Australia. https://doi.org/10.1111/j.1399-3054.1975.tb03806.x

Gils, J., Chong, C., Lumis, G. (**2004**) container nursery stock response to recirculated nutrients. ISHS Acta Horticulturae 630: XXVI International Horticultural Congress: Nursery Crops; Development, Evaluation, Production and Use.

Handreck, Kevin. Black, Neil. (**2010**) Growing media for ornamental plants and turf. 4th Ed. University of New South Wales Press. Australia.

Harris, G.L., Hodgkinson, R. A., Scott, M., Mason, D. J., and Pepper, T. J. (**1997**). Impact of hardy ornamental nursery stock (HONS) systems on the environment: losses of nutrients and agrochemicals. Agricultural Water Management 34: 95-110.

Heise, S and Reimer, G. (**2017**) Two-year comparison of long-term fertilisers in standard trees in Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis. VuB. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Heise, S. (**2016**) Attempts to remedy tip dieback in field-grown privet in Annual Report 2016. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis in VuB. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Heise, S. (**2018**) Comparison of stabilized nitrogen fertilisers for field-grown trees in Annual Report 2018. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis in VuB. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Hewson, A and Hutchinson, D. (**2014**) Hardy nursery stock - management of stock plants. HDC Factsheet 14/04.

Hojjatie, M. and Carney, F. (**2014**) Review of analytical methods for slow and controlled release fertilisers. International Fertilizer Industry Association (IFA).

Holmes, S. and Adlam, J. (**2006**) Water quality for the irrigation of ornamental crops. HDC Factsheet 15/06.

HSE. (**2023**) Biostimulants and plant protection product regulation. Health and Safety Executive. Retrieved 23.06.2023 from https://www.hse.gov.uk/pesticides/pesticides-registration/active-substances/biostimulants.htm.

ICL (**2022**) Maximise nutrient use efficiency with CRF. Retrieved 20.06.2023 from Controlled Release Fertilisers – Meeting the Needs of the Crops | ICL UK (icl-growingsolutions.com).

ICL (**2023**) An introduction to controlled-release fertilizers. Retrieved 15 July 2023 from https://icl-growingsolutions.com/agriculture/knowledge-hub/an-introduction-to-controlled-release-fertilizers/

Kelting, M., Harris, J. R., Fanelli, J., & Appleton, B. (**1998a**). Humate-based biostimulants affect early post-transplant root growth and sapflow of balled and burlapped red maple. *HortScience* HortSci, 33(2), 342-344. Retrieved May 30, 2023, from https://doi.org/10.21273/HORTSCI.33.2.342

Kelting, M., Harris, J. R., Fanelli, J., & Appleton, B. (**1998b**). Biostimulants and soil amendments affect two-year posttransplant growth of red maple and Washington hawthorn. *HortScience* HortSci, 33(5), 819-822. Retrieved May 30, 2023, from https://doi.org/10.21273/HORTSCI.33.5.819

Kleiber, T. Golcz, A. Golcz-Polaszewska, M. (**2019**) Applicability of fertigation in cultivation of selected taxa of ornamental shrubs. *Journal of Elementology.* 24 (1): 233-243. DOI: 10.5601/jelem.2018.23.1.1600

Landis, T. D. and Kasten Dumrose, K. (**2009**) Using polymer-coated controlled-release fertilizers in the nursery and after outplanting. Forest Nursery Notes. Winter 2009.

Lawrencia, D., Wong, K., Low, D.Y.S., Goh, B.H., Goh, J.K., Ruktanonchai, U. R., Scoottitantawat, A., Lee, L.H., and Tang, S.Y. (**2021**) Controlled release fertilizers: A review on coating materials and mechanism of release. *Plants*. 10:238. https://doi.org10.3390/plants10020238

MAFF (**1988**) Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209) (6th edition) The Stationery Office, London.

Maher, M. J., Campion, G. and Walshe, P. E. (**2002**) Nutrient loss from nursery stock grown in containers. Project 4745. Teagasc. Dublin.

Majsztrik, J., Owen, J.S. (**2020**) Improving nutrient management in the cultivation of ornamental plants in greenhouse, container and field production. Chapter in *Achieving* *sustainable cultivation of ornamental plants*. Ed. Reid, M. Burleigh Dodds Science Publishing. Cambridge, UK. http://dx.doi.org/10.19103/AS.2020.0066.11

Maxwell, K and Johnson, G. N. (**2000**) Chlorophyll fluorescence - a practical guide. Jounal of Experimental Botany. 51(345) 659:668.

Mills H. A, Jones J. B Jr. (**1996**). Plant analysis handbook. II: a practical sample, preparation, analysis and interpretation guide. Athens (GA): Micromacro Publishing. 422 p

Monaghan, J. (**2001**) Heathers - a study of potential improvements in nutrition. HDC project HNS 96a.

Muñoz-Huerta, R F., Guevara-Gonzalez, R. G., Contreras-Medina, L. M., Torres-Pacheco, I. Prado-Olivarez, J. and Ocampo-Velazquez, R. V. (**2013**) A review of methods for sensing the nitrogen status in plants: advantages, disadvantages and recent advances. *Sensors*. 13: 10823-10843.

Owen, W. G. (**2019**) Leaf tissue nutrient sufficiency ranges for four *Heuchera* cultivars by chronological age. *HortScience* 54(10):1751-1756. https://doi.org/10.21273/HORTSCI14222-19

Ozyhar, T., Mughini, G., and Marchi, M. (**2019**). Influence of biostimulant application in containerized Eucalyptus globulus Labill. seedlings after transplanting. *Dendrobiology* 2019, vol. 82: 17-23. Retrieved 30.05.2023 from http://dx.doi.org/10.12657/denbio.082.003

Pennell, D. Holmes, S. and Hutchinson, D. (**2013**) Study to review and improve nutrient management in container grown nursery stock. AHDB project HNS 189.

Proe, M. F. (**1994**) Plant Nutrition. In Forest Practice. Bulletin 11. Forestry Commission. 4:37-65.

RB209 (**2010**). Fertiliser Manual. Defra, 8th Edition, June 2010.

Schachtschneider, M-L., Daum, D., Dinklage, S., and Lösing, H. (**2016**) Suitability of various rapid testing processes to determine the nutrient content of tree crop saps *in Annual Report 2016*. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis. VuB. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Schachtschneider, M-L., Daum, D., Schacht, H., and Lösing, H. (**2018**) Determination of reference values for sufficient nitrate and potassium contents in plant sap from *Hydrangea paniculata* and common hornbeam in *Annual Report 2018*. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis. VuB.

Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Schoeters, L,. Adriaenssens, S., Van Haecke, D., Deckers, S., and Elsen, A. (**2021**) Sustainable fertiliser use in field-grown ornamental crops. Translated by AHDB. PCS, Belgium. Retrieved https://horticulture.ahdb.org.uk/knowledge-library/translated-publications-from-pcs-belgium-covering-technical-topics-relevant-to-ornamental-crops

Scoggins, H.L. (**2005**) Determination of optimum fertiliser concentration and correstponding substrate electrical conductivity for ten taxa of herbaceous perennials. HortScience 40(5):1504-1506.

Scott, M. (**2004**). Nursery stock propagation: nutrition of rooted cuttings in modular trays. HDC project HNS 90.

Scott, M. A. (**1994**). Container nursery stock: investigation of use of controlled release fertilisers under protection. HDC project 43.

Scott, M. A. (**1996**) Evaluation of computer simulation models for advice on the availability of nutrients from controlled release fertilisers. HDC project 43b.

Smith, E. M. (**1978**). Foliar analysis survey of woody ornamentals. Ohio Agricultural Research Centre Circular 236, 30-34.

Stevens, R. Ed. (**2003**). Nutrient charting. The nursery papers. No. 2003/03. NGIA. Horticulture Australia. ISSN: 1326-1495.

Stirling, C. B. (**1996**) Literature review of critical nutrient thresholds and wider aspects of nursery stock nutrition. HDC Project HNS 57. Final report.

Storer, K and Berdeni, D. (**2022**) EEF WP1 Evidence needs to enable effective usage of plant biostimulants. Creating an Enabling Regulatory Environment for Enhanced Efficiency Fertilisers. Project 31280. Defra. Retrieved 30.05.22 from: https://randd.defra.gov.uk/ProjectDetails?ProjectId=20585.

Talbot, D. (**2016**) Evaluating the potential of plant growth regulators to limit plant growth on tree and hedging species. AHDB project HNS 187a.

Taylor, B. K and Goubran, F. H. (**1976**). The phosphorus nutrition of the apple tree. II. Effects of localized phosphate placement on the growth and phosphorus content of split-root trees. Australian Journal of Agricultural Research 27(4) 533 - 9 http://www.publish.csiro.au/CP/AR9760533.

Terlingen, J. G. A., Radersma, S., Out, G. J. J., Hernández-Mártinez, J., and Raemakers-Franken, P. C. (**2016**) Current development in controlled release fertilisers. Proceedings No. 781. International Fertiliser Society.

VuB. (**2015**) Testing the partially coated product Granustart CRF Allround in nursery production in **Annual Report 2015**. Trialling and Advisory Circle. VuB. Chamber of Agriculture Schleswig-Holstein Horticultural Centre. Masters Thesis in VuB. Retrieved 23.06.2023 from https://horticulture.ahdb.org.uk/knowledge-library/translated-vub-annual-reports-covering-technical-research-projects-of-relevance-to-hardy-nursery-stock.

Appendices

Appendix 1. Survey template used for grower engagement/feedback at HortScience Live, 2020 and for direct engagement.

HNS 200 – Fertiliser use questionnaire

Name	
Email address	

Nutrient monitoring practices

Do you carry out routine soil analysis? (Field HNS)	**Yes**	**No**
Do you carry out growing media analysis to determine fertiliser requirements (Container HNS)	**Yes**	**No**
Do you carry out an irrigation water analysis annually	**Yes**	**No**
Do you monitor EC through the season?	**Yes**	**No**
Do you monitor leaf chlorophyll through the season?	**Yes**	**No**
Otherwise, how do you determine when to apply fertiliser?		

Nutrient application:

Field HNS		
Do you base nutrient application on soil analysis results?	**Yes**	**No**
Do you apply nutrients as 'Straights'	**Yes**	**No**

Do you apply nutrients as formulations	**Yes**	**No**
Do you apply organic fertilisers e.g. compost / manure	**Yes**	**No**
Do you use slow release 'N'	**Yes**	**No**
Do you apply manufactured fertilisers as a single application or do you split the dose	**Single**	**Split**
How do you decide how much fertiliser to apply?		
Container HNS		
Do you apply solely CRF?	**Yes**	No
Do you apply liquid feed to all crops?	**Yes**	No
Do you just use liquid feeds to correct nutrient deficiencies?	**Yes**	No
Do you apply a combination of CRF and liquid feed	**Yes**	No
Please expand if the above apply to certain crops or container size		

Are there any areas where knowledge and/or recommendations are lacking or not easily available?

Specific production systems? E.g. young trees, transplants, liners	

Specific tree growth stages?	
Key species?	
Any other?	

How do you prefer to engage with updates or recommendations?

Briefing notes	
Bound publication	
Workshops	
Video	
Smartphone app	
Any other?	

Contact Us

Jill England:. Jill.England@adas.co.uk, 01304 389186

David Talbot, David.Talbot@adas.co.uk, 07817 260 087

Appendix 2. Leaf tissue sufficiency ranges for four *Heuchera hybrida* L cultivars, with different leaf colours at three growth stages (3 weeks after transplant WAT; young growth, 6WAT, active growth; and 9WAT mature growth and/or bloom) weeks after transplant. Plants were grown n nitrogen (N), based on NPK supplied as 15:1.7:12.5 containing 1.9% ammoniacal-N and 13.1% nitrate-N with a constant level of water-soluble micronutrient blend (**Owen, 2019**)

Cultivar and weeks after transplant (WAT)	Elemental nutrient										
	Macronutrients						Micronutrients				
	Total nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Iron	Manganese	Zinc	Copper	Boron
	(%)						(mg·kg^{-1})				
Black Beauty											
3	3.43–3.83	0.55–0.58	2.40–2.68	1.01–1.10	0.39–0.41	0.38–0.39	105.2–155.0	61.9–72.2	34.9–39.4	6.3–7.1	28.0–28.5
6	3.79–4.00	0.72–0.75	3.00–3.06	1.07–1.26	0.37–0.40	0.40–0.45	128.5–189.6	57.2–67.5	54.6–56.1	7.1–7.2	29.9–33.5
9	3.45–3.63	0.52–0.55	2.21–2.27	0.88–0.95	0.31–0.33	0.45–0.57	124.2–145.5	43.7–44.7	56.4–59.4	9.7–9.8	41.3–46.2
Cherry Cola											
3	3.82–3.96	0.57–0.60	2.80–3.29	1.14–1.34	0.41–0.44	0.41–0.47	116.6–137.1	67.2–70.7	38.6–41.6	6.0–7.9	36.6–38.2
6	4.26–4.35	0.64–0.72	2.87–2.92	1.83–1.91	0.46–0.45	0.47–0.56	115.9–117.2	58.1–68.4	41.6–48.9	8.3–9.2	48.6–55.5
9	3.92–4.18	0.64–0.68	2.68–3.03	1.36–1.66	0.35–0.37	0.59–0.66	106.8–111.7	58.4–65.7	58.5–71.8	9.9–10.3	65.3–67.5
Marmalade											
3	3.24–3.27	0.47–0.50	1.92–2.27	0.70–0.72	0.25–0.27	0.45–0.52	137.5–154.2	62.6–73.5	41.7–47.8	6.4–7.1	30.8–33.6
6	3.98–4.09	0.57–0.61	2.60–2.66	0.89–1.07	0.32–0.34	0.47–0.48	197.0–209.0	62.6–73.5	49.2–50.8	7.4–8.4	34.8–36.8
9	2.98–3.25	0.37–0.39	1.45–1.58	0.73–0.77	0.23–0.24	0.45–0.59	146.7–203.4	44.3–46.0	69.0–70.8	10.3–10.9	37.8–37.9
Peppermint Spice											
3	2.87–3.15	0.37–0.44	1.64–1.70	0.89–0.94	0.27–0.30	0.39–0.41	50.3–58.4	54.2–65.5	35.1–35.9	5.5–5.8	30.3–30.6
6	3.58–3.74	0.39–0.40	2.01–2.15	1.22–1.26	0.32–0.33	0.35–0.43	65.5–73.4	48.4–50.2	36.1–38.8	6.0–6.2	34.5–34.7
9	2.78–3.23	0.22–0.30	1.10–1.35	1.15–1.21	0.29–0.33	0.36–0.38	51.6–65.4	45.5–51.6	45.6–47.7	6.4–8.1	36.1–36.4

