Project title:	Nutrient management in Hardy Nursery Stock (NutrHONS project)
Project number:	HNS 193
Project leader:	D J Adlam, Dove Associates N Bragg, Bulrush Horticulture Ltd
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Date project commenced:	01 May 2015
Date project completed	31 December 2017 (Expected)

DISCLAIMER

[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.

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GROWER SUMMARY

Headline

The trial aims to establish a protocol for collecting and monitoring the nutritional inputs and outputs of container hardy nursery stock growing systems. Several on-nursery hand-held pieces of equipment have been tested across a range of ornamental species and the readings compared to traditional laboratory techniques.

Background

In the second year of the project, a third site, James Coles Nurseries at Leicester, was brought into the trial, which aimed to increase the range of conditions and establish the practicality of growers using the hand held equipment on site. The Coles site proved immensely useful as it showed that some of the equipment, whilst accurate and reliable, was unsuitable for nursery use. We also experienced a supply difficulty with the atLEAF+ chlorophyll device which is currently not available. An alternative device, Apogee MC 100, was used on two of the sites. Although expensive, it has proved well suited to the programme.

Summary

The second year of this project has further refined the use of several pieces of hand-held equipment available on the market, to monitor the nutritional status of the crops in comparison to samples sent off for traditional laboratory analysis of substrates, tissue and for leachate samples. The results of the first year clearly indicated that some equipment was limited in its use with nursery stock plants, mainly due to the difficulty of extracting clean tissue sap which could then be used to measure parameters such as nitrate N values. In the second year, equipment used on the nurseries was limited to currently available pieces of equipment easy to use on the nursery.

Year 1 trends between field readings and declining levels of leaf and substrate nutrient levels appear to have been supported by this second year work.

The Apogee MC 100 was introduced into the project to replace the unavailable atLEAF^{+} device. It measures chlorophyll with the near identical wavelength led light sources as the atLEAF^{+} but it is within a closed chamber, avoiding any daylight variations. It also takes a smaller sample size of leaf making readings easier.

Skimmia , which had been very poor in terms of establishment and growth in the first year, were replaced by *Tradescanthia*. The latter is a very fast growing plant and responded well to the various fertiliser additions being used.

Similiarly to the first year, leaching levels of nutrients in the early stages after potting have caused concerns, and investigations of the release rates from CRF fertilisers has been examined. The nitrogen source was changed to Urea to reduce the initial high rate of nitrogen release experienced in year 1.

All plants were potted in week 19 and whilst the initial leaf tissue N% levels were quite good at or near potting, the N% figure levels dropped for subjects after the beginning of June and in many cases resulted in N% tissue levels being below the ‘book’ values expected for such plants. The N% in tissue from June to October clearly shows the ever decreasing level of N in tissue. This may reflect the initial release of fertiliser from the CRF granules ahead of the plants establishing an active root system, which is supported by the initial high levels of nutrients in the leachate. The result of the leaching in the early stages after potting meant that optimal levels of available N for tissues were not reached later in the crop.

Chlorophyll measurements

The chlorophyll meters have produced a degree of similarity between the N tissue content and the chlorophyll reading. In the case of the *Tradescanthia*, the plant leaf colour does naturally turn browner as it matures which late in the season gives a less accurate reading for N levels. It can however be demonstrated that for *Tradescanthia* there is a relationship between tissue N and the atLEAF^{+} for the major part of the growing season, see Figure 1.

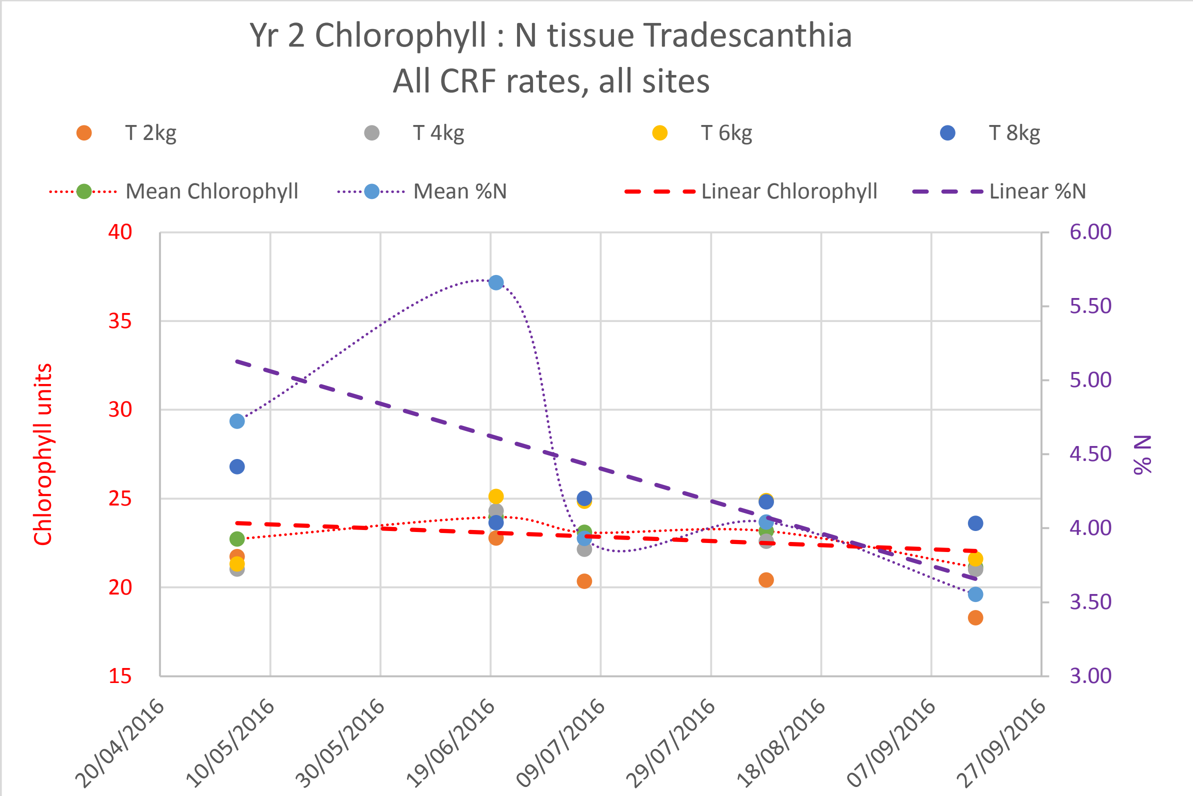

Figure 1 shows tissue v chlorophyll comparison for *Tradescanthia* across all 3 sites

The scale-like foliage of the *Chamaecyparis* makes leaf chlorophyll readings difficult to achieve. As the atLEAF$^+$ device has an open gate for reading it is possible to slide the tissue through, holding down the “Read” button and obtain an average indication of chlorophyll level. This is not a reliable method for reading and it was found that when using the Apogee MC 100 in its place with a closed chamber, it was difficult to ensure a uniform foliage thickness and avoid gaps through the scales.

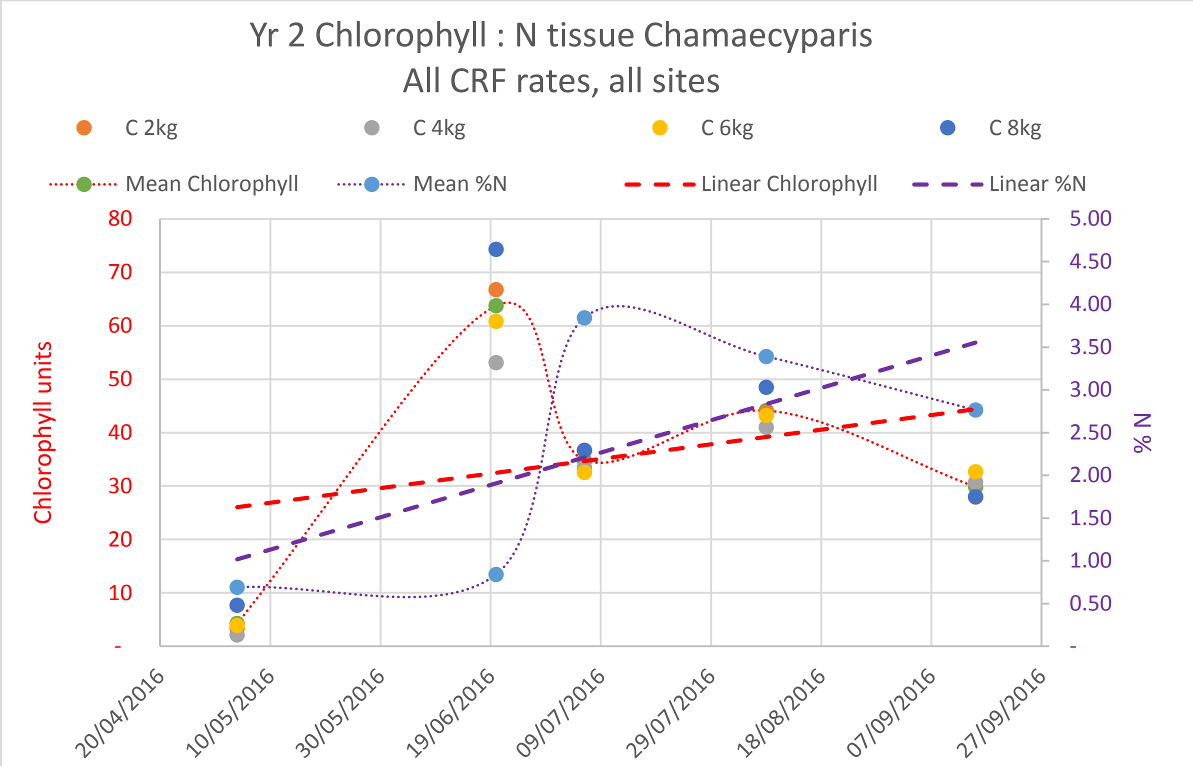

Figure 2 shows tissue v chlorophyll comparison for *Chamaecyparis* across all 3 sites

The Apogee MC 100 device was particularly effective at identifying chlorophyll colour changes before they were identified by the eye, see Figure 3.

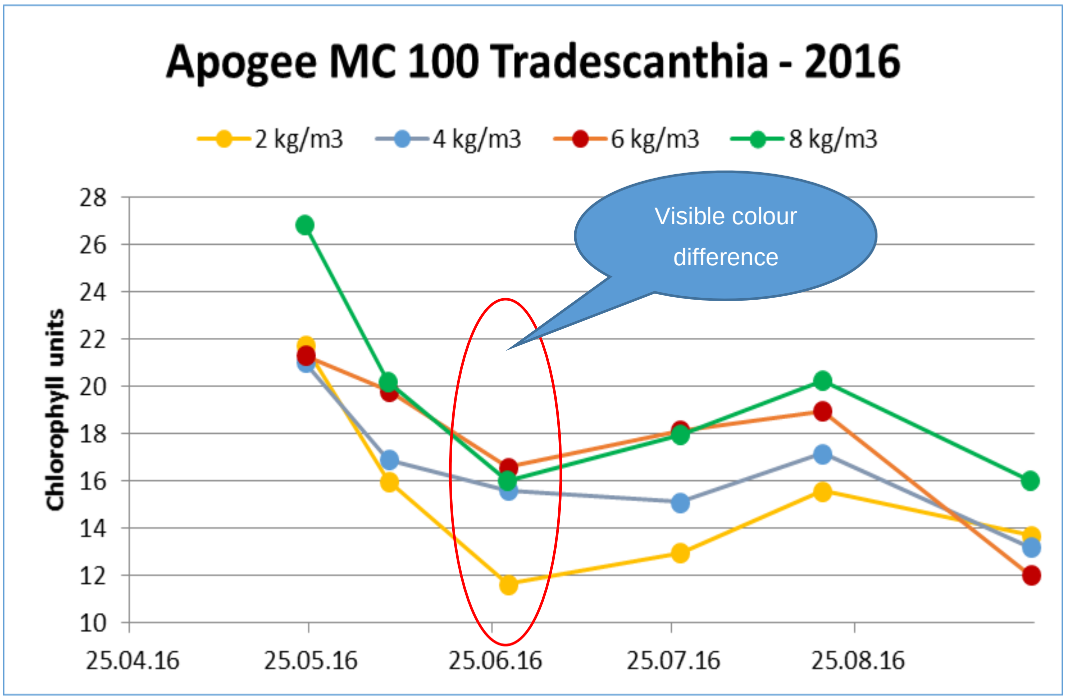

Figure 3 shows chlorophyll colour changes for *Tradescanthia* across all CRF (osmocote) rates

The Green Index system is a low-cost chlorophyll meter using the camera of an iPhone. It has continued to show promising results in the second year. At all three sites it gave a chlorophyll value that reflected the N level in the tissue reasonably well. As with other chlorophyll measuring equipment (such as the Apogee MC 100 and atLEAF+) it was subject to variations in leaf shape and texture and again was not as accurate as the leaf colour changed in the autumn. Overall as a guide to plant nutrient status the Green Index was easy to use and cost effective, but note that the system did not detect the early colour changes in leaves, unlike the Apogee MC 100.

Substrate conductivity equipment

Considering that the Procheck is sensing the electrical conductivity of the substrate, rather than any direct plant response, the values for EC recorded in the substrate did have a very similar trend to the N% recorded in the leaf tissue, at least for the *Tradescanthia*, (Figure 4). During the season *Buddleja* showed a more erratic pattern due to the EC rise in the substrate at the time of trimming (Figure 5).

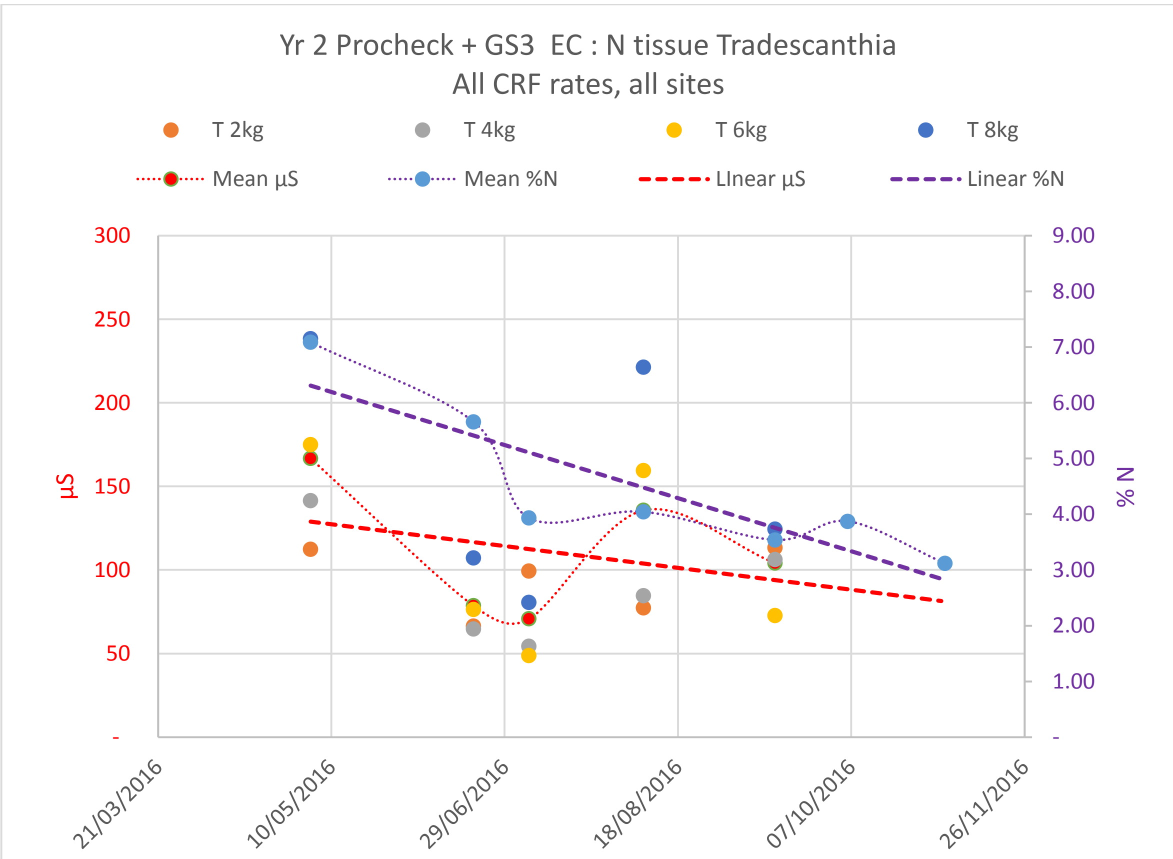

Figure 4 shows EC v N levels for *Tradescanthia* across all 3 sites

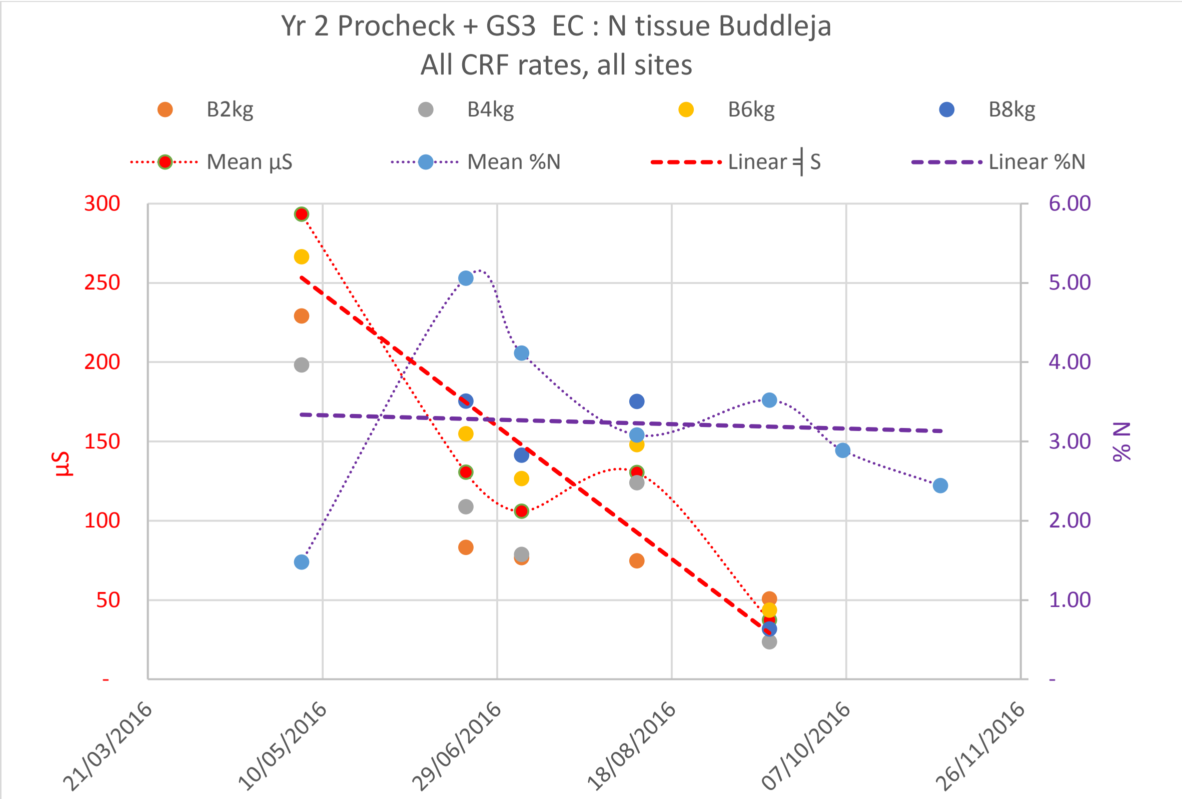

Figure 5 shows EC v N levels for *Buddleja* across all 3 sites

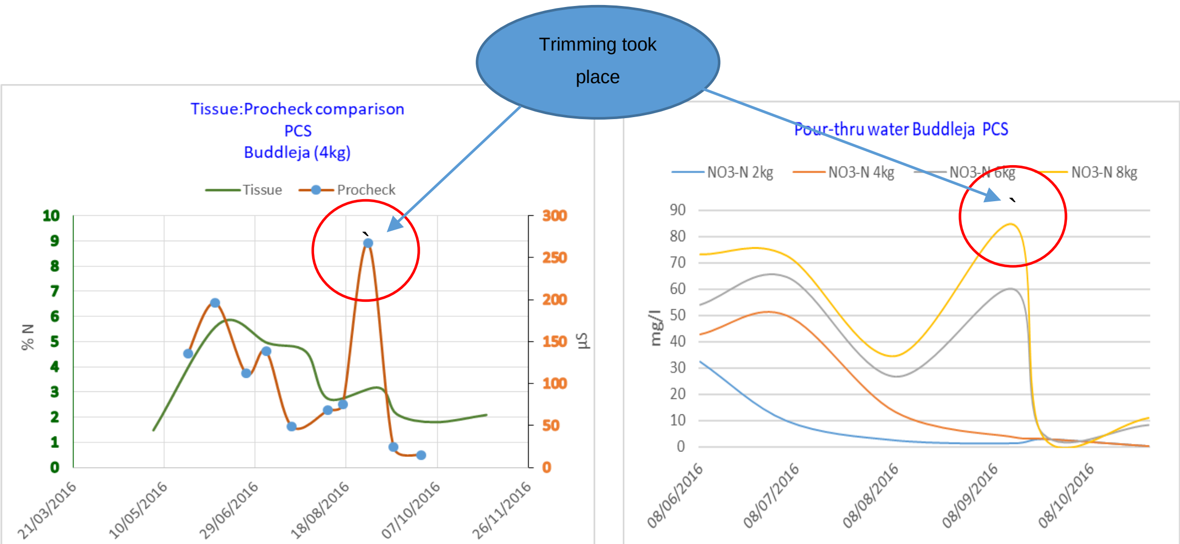

Figure 6 shows EC v N levels and leaching levels for *Buddleja* when trimmed

Financial Benefits

Investment in monitoring equipment will be needed, but this may only be in the order of £2,000-£3,000 to make the monitoring possible. Taking the value of crops being monitored, the capital expenditure is quite low. The effect on a grower's sales when they have a nutrition problem can be very high. We asked a group of seven nursery stock growers what the crop losses were from nutritional problems. No one was able to quantify these losses.

For many Growers there can be losses of plants through production of between 5-10% due to disease, pest or nutritional effects. If it is accepted that on average the return per ha for HNS is £750,000, then a loss of 7.5% would equate to £56,000. If we then assumed that nutritional losses or under performance due to inadequate nutrition is 2-3% then this would equate to £19,000.

The new atLEAF+ chlorophyll meter priced at £350.00 or the Procheck EC meter at £750.00 both have the ability to ensure marketing targets of crops valued at tens of thousands of pounds are met. One grower comment was that equipment such as the Apogee MC100 at over £2,000 was of value if it could advise of nutrients lacking in the crop and saved it.

The table below shows the cost of nutrients added to and leached from the 6 pots contained in the Pour-thru units at PCS on *Viburnum*. The unit price of nitrogen was costed at £600/tonne. Note that the value of any mineralised N from the substrate would be included in the leachate data but no value is available for that part of the analysis results.

Kgs CRF/m^3	2kg/m^3	4kg/m^3	6kg/m^3	8kg/m^3
Cost of N added(CRF + PG mix + Urea)	£0.01238	£0.01707	£0.02535	£0.02812
Cost of N in leachate	£0.00700	£0.01200	£0.02000	£0.02400

Table showing nutrient costings

Using the monitoring equipment that detects nutrient content prior to visual detection enables a greater reactive approach to crop nutrition that has both environmental and financial gains.

Action Points

If growers are going to monitor crops on nurseries then:

a) Dedicate a person and give them the skills for accurate sampling across the selected subjects,

b) Use selected marker crops on the nursery, potted into a substrate used widely across the nursery for sampling,

c) During the first few years of monitoring, laboratory analysis will be needed to establish the benchmark of nutritional values for specific crops,

d) Be prepared to liquid feed a crop with CRF added to maintain targeted growth.

e) Be aware that some husbandry work can affect substrate EC levels and nutrient uptake.

f) Clearly label tissue samples so that accurate identification can be made even if they don't come back from the laboratory in same order as sent.

g) More frequent sampling (e.g fortnightly, or weekly intervals) is necessary in the first year, so that trends can be developed even if tissue samples get lost or damaged.

SCIENCE SECTION

Introduction

In the first year the trial was set up at two testing sites, Greenmount College in Northern Ireland (NI) and PCS at Destelbergen near Ghent in Belgium. At both sites a fully replicated, randomised trial involving four plant species and four levels of fertiliser was set up. For the first year five hand-held pieces of equipment were used regularly at the trial sites to derive values and these values were then compared to traditional laboratory samples of leaf tissue and substrates. Additionally, the setup of the trials enabled the collection and analysis of leachate from a number of pots in each treatment to assess nutrient loss. Irrigation and rainfall inputs were recorded at both sites. For the second year of the trial both trial sites at Greenmount and PCS were set up and an additional trial site was set up at Coles of Leicester (Syston site). This was done to assess the implications of doing such trial work on a working nursery and also to give additional data sets from a different geographical site. In addition to the extra site at Coles, Osberton Grange nursery have successfully used the atLEAF+ device on an Azalea crop and FP Matthews used the Horiba Laqua Twin in fruit tree foliage but failed to extract any sap.

In the second year the substrates and fertilisers remained similar to the first year, the only change being the replacement of CAN (calcium ammonium nitrate - additional N fertiliser to avoid immobilisation on the Woodfibre component) with Urea. The use of Urea was based on its slow availability and hence the avoidance of initial conductivity spikes with the use of CAN, which had been thought to contribute to the initial leaching losses recorded in the first year.

In terms of plant species used at the main trial sites the only change was that *Skimmia*, which had been very poor in terms of establishment and growth in the first year, was replaced by *Tradescanthia*. The latter is a very fast growing plant and the team felt it would respond well to the various fertiliser additions being used.

Based on year 1 data and experience the following changes would be made to the hand-held equipment:

Firstly the use of the 'dip sticks' was dropped altogether as it had been found that the expressed leaf sap was highly coloured and dirty and without further treatment then it could not be reliably used as an 'on-nursery' technique. As will be seen from the year 2 data sets the expression of sap from many of the plants used is very difficult to achieve, and is probably also true of a wide range of Nursery stock and tree subjects. It is particularly difficult in the field, such that equipment reliant on the expression of sap are probably more suited to only very fleshy subjects and only undertaken after a pre-preparation of the collected tissue by, for example, freezing first to disrupt the tissue cells.

Therefore in year 2 the concentration of efforts was on the Chlorophyll fluorescence measurements and the monitoring of EC checks on the substrates, plus the continued laboratory measurement of substrate, tissue and leachate samples.

Materials and methods

Plants

Plant species used were *Tradescanthia*, *Viburnum*, *Chamaecyparis* and *Buddleja*. The replacement for the semi ericaceous *Skimmia* in the trial was Azalea at Osberton nurseries.

The use of *Skimmia* proved difficult to grow in a research environment and was changed to a herbaceous subject *Tradescanthia*. *Tradescanthia* provided adequate foliage for sap expression and appeared very efficient at uptake of available nutrients.

Viburnum, *Chamaecyparis* and *Buddleja* were used in year 2 trials. Due to the rapid growth of *Buddleja* it was cut back in August, which gave variations in the height records as well as variations in the nutrient content of the pour-thru water. The *Viburnum*, *Chamaecyparis* and

Buddleja were all grown from plug material. The *Tradescanthia* was grown from bare root material.

Plants were grown in a peat wood fibre mix, identical to year 1, in 1.5 litre pots.

Six plants were placed in a Pour-thru device (or lysimeter) that collected rainfall and irrigation that ran through the substrate. The water volume was measured at monthly intervals or more if the volume collected was excessive. In periods of heavy rainfall this was more frequent than periods of irrigation. In periods of heavy rainfall 500 ml samples were retained in a darkened refrigerator and added to a 500 ml sample taken at the end of the month for nutrient content analysis. A further 30 plants were placed around the Pour-thru device for the purposes of destructive and non-destructive tissue and substrate sampling. Substrate and tissue samples were not taken from the Pour-thru device plants. No more than one substrate sample was taken from a pot.

Equipment

Full details of the equipment used in year 2 of the project are described in the year 1 report.

Horiba Laqua Twin

With the difficulty of getting the nitrogen strips to work they were dropped in year 2. Sap extraction for the Horiba Laqua Twin was achieved by taking young leaves 50mm (2inches) down from the growing tip to provide around 500ml of foliage, chopping them up and placing them in a large syringe. The syringes were then frozen for 24 hours. After thawing, the syringe can be squeezed and the sap dropped onto the sample point of the device. By using available filters a smaller sample of sap can be used on the Horiba device.

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

atLEAF$^+$

The atLEAF$^+$ has proved a cost effective chlorophyll measuring device but when we ordered an additional device we found that the manufacturer had none available and was encountering problems in producing more.

There are two LED emitters in the upper part of the aperture at two wavelengths, red at 660 nm (nano meter) and near infra-red (NIR) at 940 nm (nano meter). Light filtered through the leaf is captured by a sensor below which measures the absorbance of the leaf. The difference in transmission of the filtered wavelengths gives a measure of chlorophyll content in atLEAF$^+$ units (1-100).

The atLEAF$^+$ measured the chlorophyll levels in the plants well but is measured in open daylight. When measuring it was important that the main vein was not in the measuring point. The measurement of *Chamaecyparis* was possible with the atLEAF$^+$ by holding down the measure button while sliding the branches through the slot, which gives an average reading. In relating daylight levels to chlorophyll readings there was no influence that could be deduced.

Apogee MC100

The Apogee MC 100 was introduced into the project to replace the unavailable atLEAF$^+$ device. It measures chlorophyll with the near identical wavelength led light sources as the atLEAF$^+$ but it is within a closed chamber so avoiding any daylight variations. It also takes a smaller sample size of leaf, making readings easier.

The Apogee model MC 100 chlorophyll concentration meter measures relative chlorophyll content and outputs. The chlorophyll concentration is measured by two light emitting diodes, one emitting 931 nm and one emitting 653 nm with paired detectors giving chlorophyll concentration in units of µmol per m^2 of leaf surface. The ratio of radiation transmittance from two different wavelengths and outputs chlorophyll concentration is calculated internally from which the transmittance ratio measurement is made. The Apogee MC 100 used at Greenmount and the CCM 200 used at PCS are the same piece of equipment differently badged.

Green Index

Green Index is an iPhone App that uses the phone camera to establish the colour of the leaf to determine chlorophyll colour. The device uses a colour board to create a reference for the camera and gives a figure that is called a Dark Green Colour Index (DGCI). This App was developed to capture differences in 'greenness' between maize leaves. It captures images using the iPhone digital camera and determines the DGCI (Dark Green Colour Index) of plant leaves (between 0 and 1). It is used in conjunction with a reference board which is used as a background when taking pictures of the leaves. The green and yellow discs present in this board are known colours (standards) used by the software to calibrate differences in light conditions; the pink background increases contrast and reduces noise, and the grey colour calibrates the white balance.

Procheck

The Procheck with GS3 sensor measures the EC of the growing media and is easy to use and closely follows the tissue nitrogen levels. The device is inserted into the substrate and gives an immediate reading showing the conductivity in µS. The sensor, GS3 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 the presence of macronutrients in the growing medium.

Substrate mixes

Product Specification

Main ingredients

3 parts Dark peat 18 MM 6 parts Light peat 18 MM	80% of the mix
1 part Sod peat 18 MM	
FOREST GOLD® -------------	20% of the mix

Nutrients added per m³:
1 KG BASE 15-10-20+TE

0.1 KG UREA

3 KG LIME/DOLODUST

0.4 LITRE WETTING AGENT

CRF additions:

2, 4, 6 & 8 kg/m^3 of 8-9 month Osmocote Pro 8-9 month 16:11:10 (standard release product). This is the 2nd generation material and would be considered comparable to Nutricote, Basacote, Plantacote products of similar longevities.

Laboratory analysis

All plant tissue, substrate and water analysis was carried out at the same UK laboratory to avoid differences in the results and analysis methods. Results were given in standard UK units of milligrams/lt (mg/l), with pH carried out in a water sample. Conductivity was measured in micro Siemens (µS). Tissue samples were taken from new stems and the foliage selected was taken 50mm down from the growing point. Leaf tissue was taken from all three replicates and placed into one sample, according to the substrate CRF rates. Substrate samples were taken from the guard pots with 20^{+} samples taken from all three replicates and placed into one. Substrate samples were taken from the mid pot area, avoiding the top and bottom.

'Pour-thru' collection and analysis:

Every four weeks the volume of drained water in the lower container of the pour-thru was measured, sampled for water analysis and emptied. At the same time substrate samples were also taken and sent to the laboratory. Samples from each site were sent to the same laboratory to avoid differences in procedures. Temperature and rainfall were measured by weather stations present at each site. The amount of water received by the plants (rainfall plus irrigation) was measured by rainfall gauges. In this way run-off and nutrient leaching could be monitored to give researchers an accurate idea of the level of nutrients being used by the plants and lost through leaching.

Weather records

Hourly weather records were taken at each site covering air temperature, humidity, rainfall and light levels. Rainfall was measured in mm and light levels were measured in watts/m^2. See appendix 1, Figures 22 – 25.

Statistical Analysis Protocol

The data comprised the treatment means for four treatments (2,4,6,8kg) observed on each of 3 sites for a number of variables. Not all variables were observed and results were concentrated on the relationship of the equipment data to plant tissue analysis results. This data was available for four species (*Viburnum*, *Tradescanthia*, *Chamaecyparis*, *Buddleja*). The analysis comprised an ANOVA test of the variables and regarding the sites as randomised blocks and ignoring the dependancies between measurements taken on a plot at different times. These were regarded as being independent measurements for the purposes of the analysis.

Results

Laboratory results:

It had always been envisaged that the 3 main sites would behave differently due to their geographic position and in year 2 clear site differences have emerged. The site differences in the statistical anaylsis show that it is not possible to relate readings from one site to another.

All the plants had been potted at or around wk 19 and whilst the initial leaf tissue N% levels were at or above the standard levels, the N% figures dropped for subjects after the beginning of June and in many cases resulted in N% tissue levels being below the standard values (stated in Plant Analysis Handbook II, Mills, Benton Jones, Micro Macro Publishing Inc.) expected for such plants. Figures 7-9 show the N% in tissue from June until October and clearly show the decreasing level of N in the tissue. This may well reflect the initial release of fertiliser from the CRF granules ahead of the plants really establishing, and also supports the initial high levels of nutrients in the leachate, (Figures 10-12). The result of leaching in the early stages after potting at Greenmount meant that there was not enough available N to subsequently meet the optimal levels for the tissue requirements.

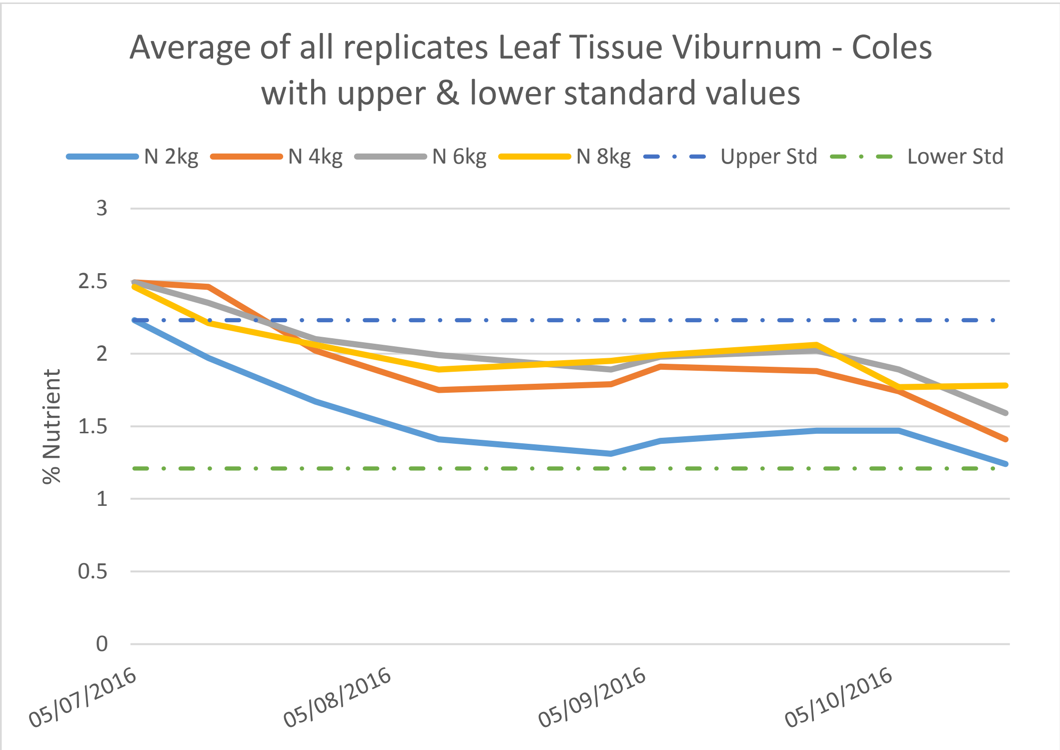

Figure 7 shows the N% in the leaf tissue levels for Coles including standard values

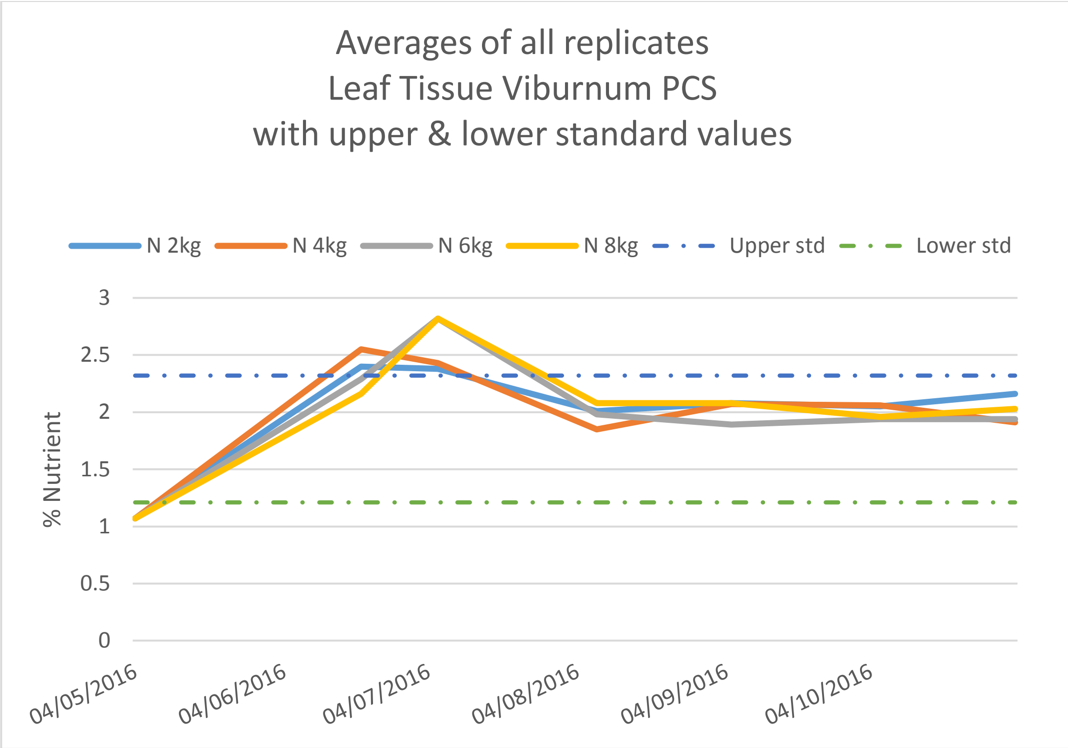

Figure 8 shows the N% in the leaf tissue levels for PCS including standard values

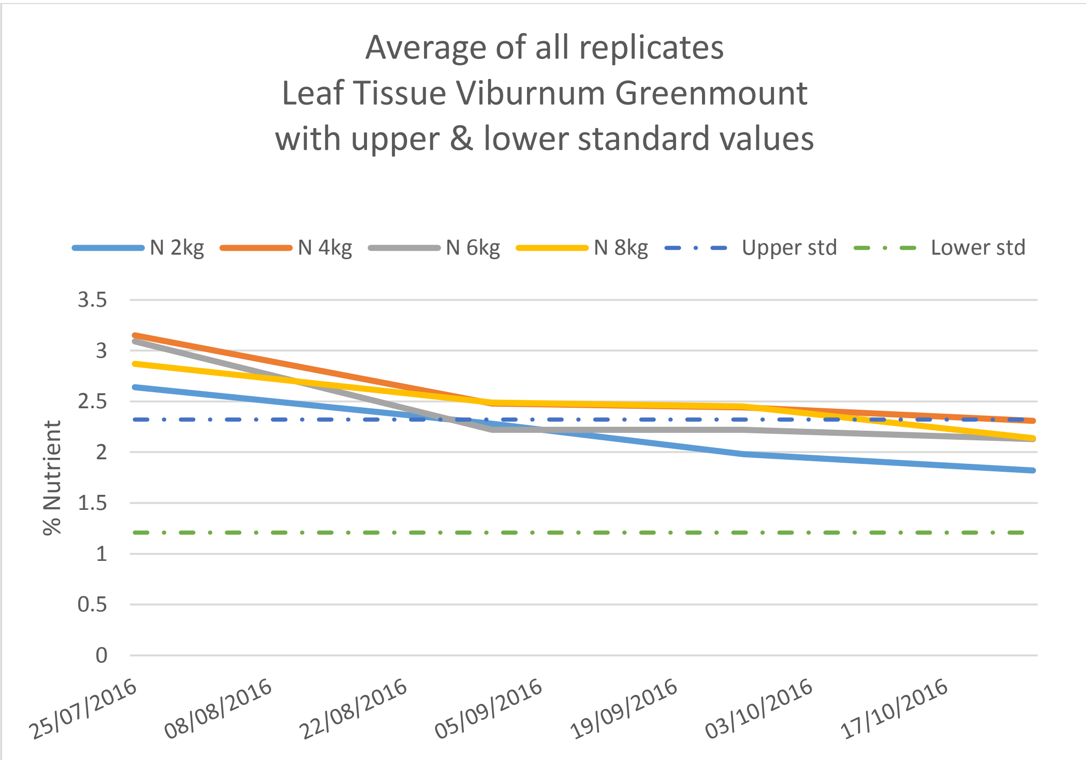

Figure 9 shows the N% in the leaf tissue levels for Greenmount including standard values

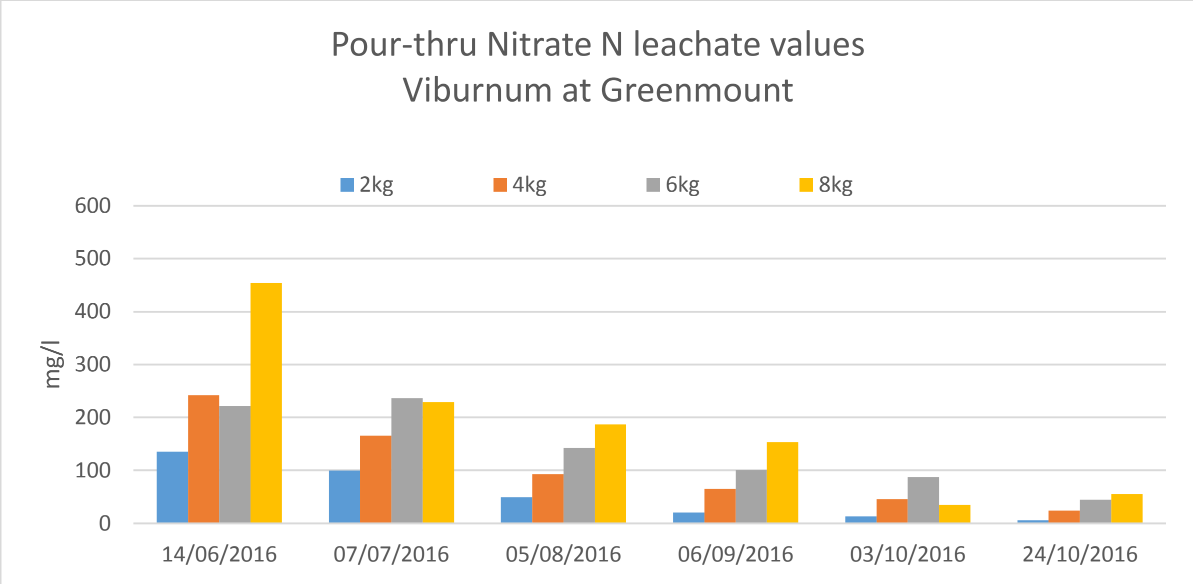

Figure 10 shows nitrate N leaching at Greenmount for *Viburnum* across all CRF rates (no error bars due to composite samples)

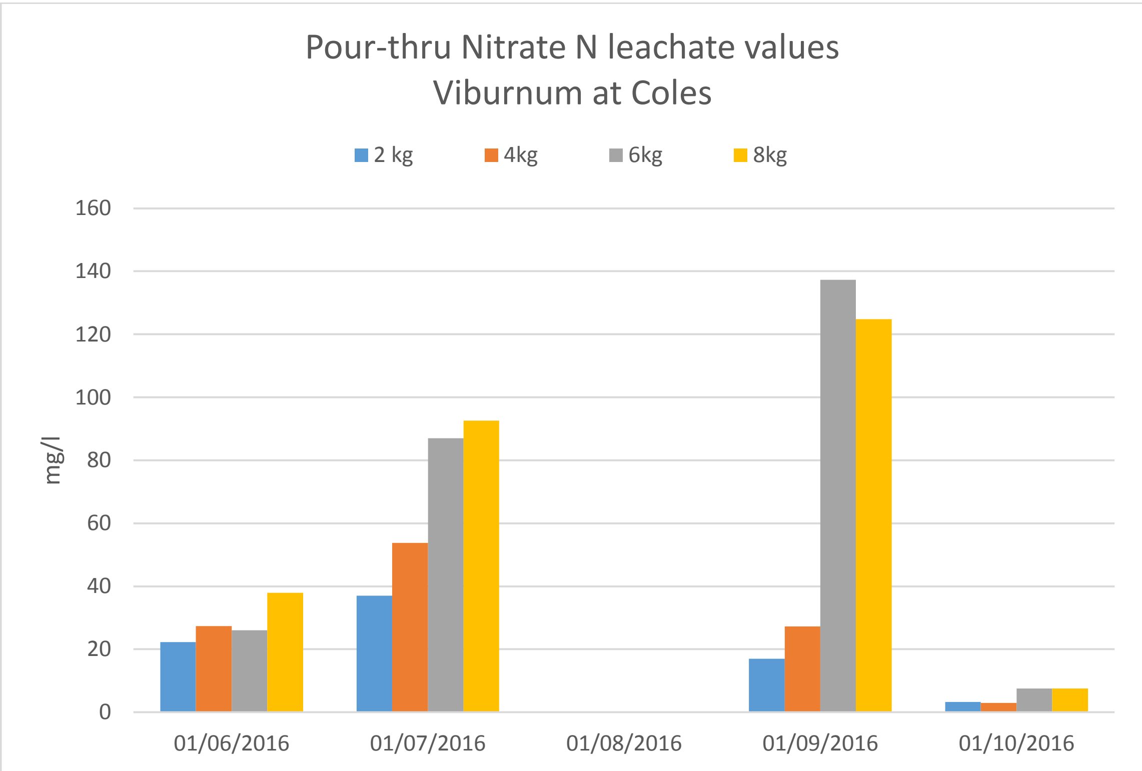

Figure 11 shows nitrate N leaching at Coles for *Viburnum* across all CRF rates (no error bars due to composite samples)

In Figures 10-12 the slightly unusual feature is the apparent late release of Nitrate at Coles. The Greenmount and PCS sites follow the predicted pattern of initial high leaching values marrying with the initial release from the CRF's. This is followed by a decline through the season as the plants are fully established and utilising the nutrients, which are apparently insufficient to meet the demands of the plants fully. From the Figure 7 there is an indication that during the latter part of the season, the leaf tissue N levels fell and in the case of the 2kg CRF rate, below the quoted book values. This is possibly because too much of the soluble N had been leached early in the trial period and hence there was insufficient N to match the plant requirements later on in the season. The rainfall at Coles was the lowest overall, but there appears to have been an accumulation of nutrients leached later in the season.

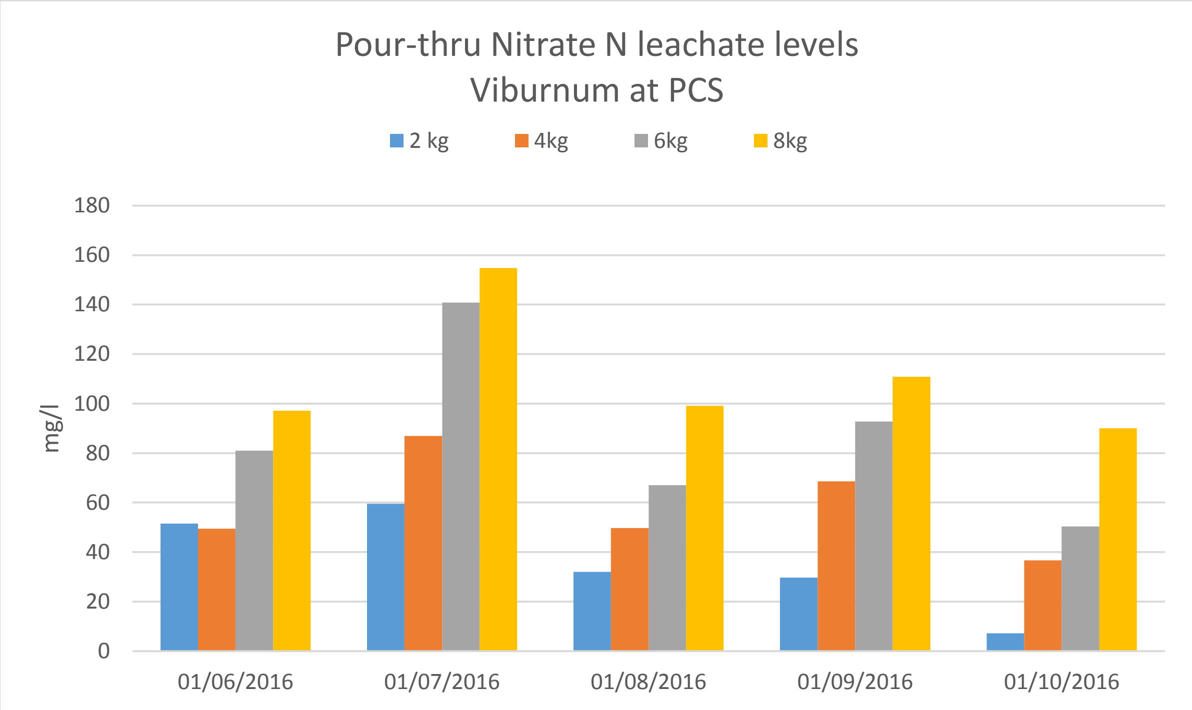

Figure 12 shows nitrate N leaching at PCS for *Viburnum* across all CRF rates (no error bars due to composite samples)

Equipment ability to register N levels in a crop

atLEAF+ and Apogee MC 100/CCM Chlorophyll measurement

With the non-availability of the atLEAF+ device in year 2, an alternative, the Apogee MC100 was purchased by CAFRE. An identical device, marketed under a different name to the CCM device that was available at PCS.

Apogee & CCM Chlorophyll measurement

The Apogee MC 100 device was particularly effective at identifying chlorophyll colour changes in the *Tradescanthia* before they were identified by the naked eye.

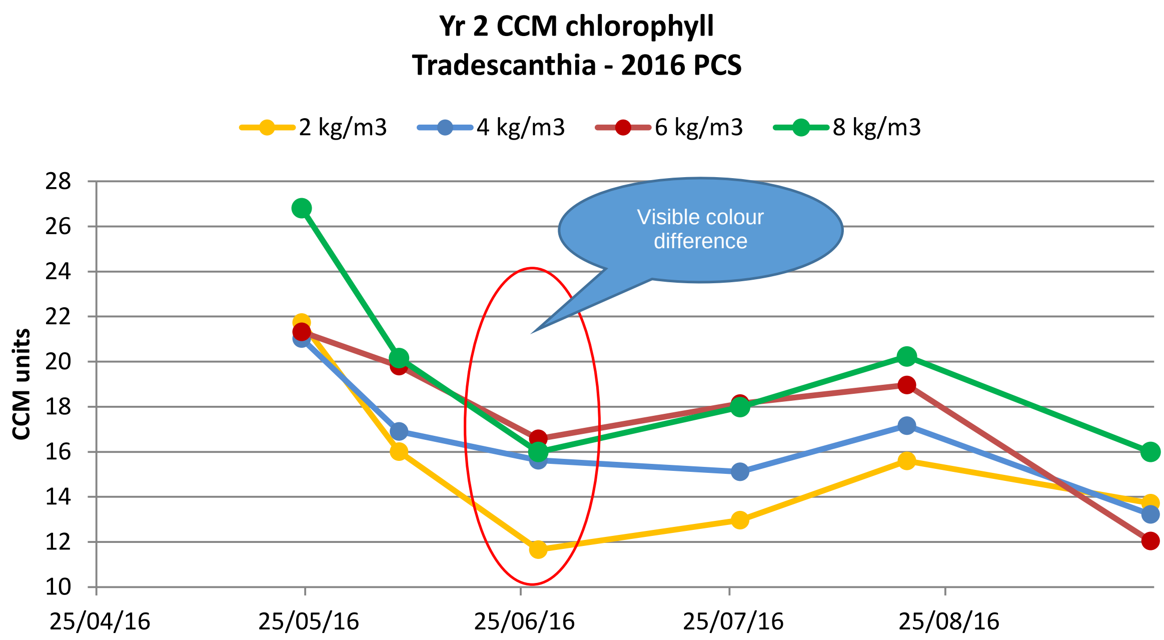

Figure 13 shows chlorophyll readings from the CCM for *Tradescanthia* at PCS across all CRF rates. The Green Index system did not detect the early change in leaf colour, see Figure 14.

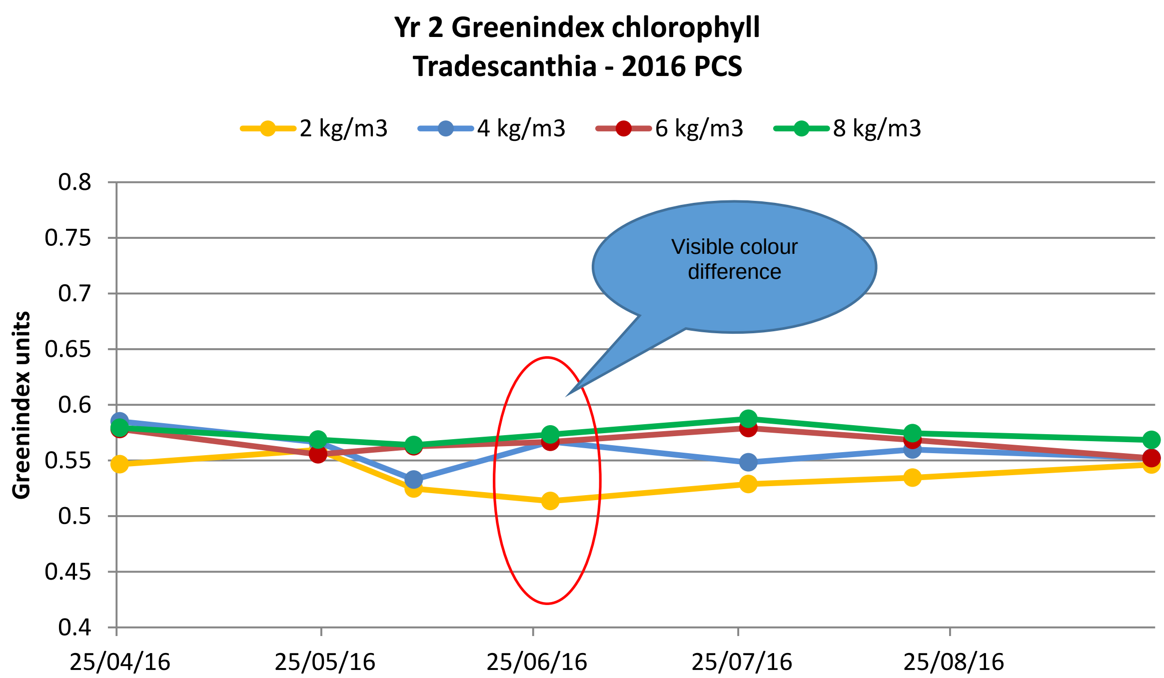

Figure 14 shows Chlorophyll readings from the Green Index data on *Tradescanthia* at PCS

The statistical analysis of the Apogee device on Tradescanthia has a highly significant p value *($p < 0.05$)* with variations between the sites showing a *p* value of 0.009. On Viburnum the device also showed high significance *($p>0.05$),* with Buddleja *($p < 0.05$)* and Chamaecyparis *($p < 0.05$)*. This device whilst expensive is showing good potential as a usable indicator of N levels in tissue.

Azaleas

Trials using the atLEAF$^+$ were also carried out by the nursery staff under normal commercial conditions. Figure 15 shows the tissue analysis of Azalea Blue Danube. It also shows the maximum and minimum nitrogen levels for optimum azalea growth taken from Mills and Jones Plant Analysis Handbook. Figure 16 shows the atLEAF$^+$ readings taken from the plant over the same period as the tissue samples.

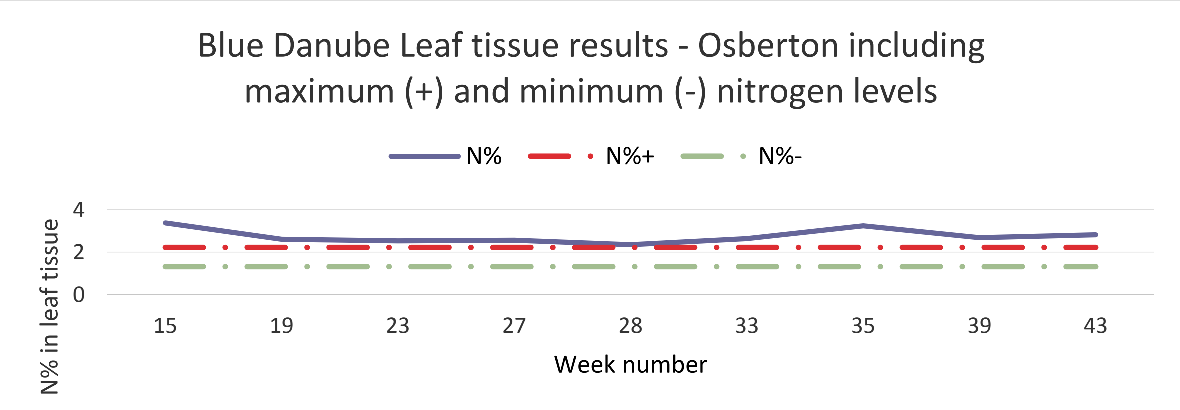

Figure 15 shows tissue results for Blue Danube including max/min levels for optimum growth

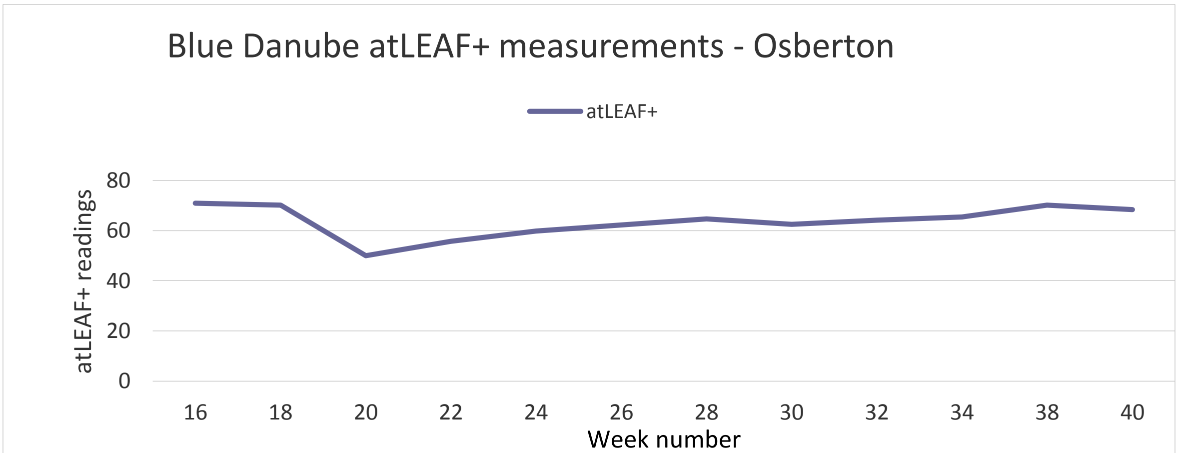

Figure 16 shows the atLEAF+ results for Blue Danube at Osberton

Green Index Chlorophyll measurement

The Green Index system is a low-cost chlorophyll meter using the camera of an iPhone. It has continued to show promising results in the second year. At all three sites it gave a chlorophyll value that reflected the N level in the tissue better in the *Viburnum* than *Tradescanthia* and Chamaecyparis. It was subject to variations in leaf shape and texture and was not as accurate when leaf colour changed in the autumn. As a guide to plant nutrient status in selected crops it has the ability to be of value in identifying trends over time. The long term use of the calibration board does cause wear and over a period of time a replacement may be necessary. The Green Index system had an overall *p* level of 0.0265. There were differences between sites and treatments that showed no significance.

Procheck and GS3 EC measurement

The Procheck and GS3 sensor were easy to use requiring only insertion of the GS3 sensor into the substrate. Several readings from a pot are advisable to ensure a truly representative result. The “soil-less” setting was used on the device. It was found that readings can be unrepresentative if taken straight after rainfall or irrigation. In the case of the readings taken in June at PCS on *Viburnum*, the device gave a low EC reading during a period of prolonged rainfall. It should be noted that although all the different crops had the same rate of CRF they maintained a substrate EC relative to their ability to assimilate the nutrients released. *Tradescanthia* assimilated far more nitrogen, even at the 8kg/m³ rate than the other subjects and therefore showed a lower substrate EC. The high growth rate of the *Buddleja* required a trim. The point at which the trim took place is seen as a high spike in substrate EC, See Fig 17, showing the lack of nutrient uptake and increased leaching when the husbandry was carried out.

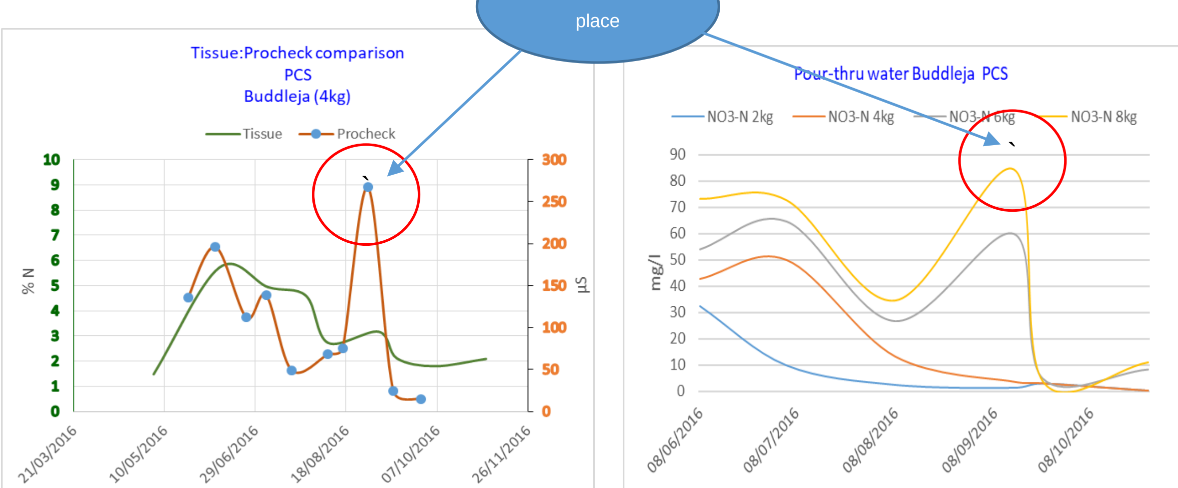

Figure 17 shows EC v N levels and leaching levels for *Buddleja* when trimmed

The Decagon Procheck with GS3 sensor results were highly significant with Viburnum *($p < 0.05$)*, Tradescanthia *($p < 0.05$)* and Buddleja *($p < 0.05$)*. Chamaecyparis showed no significance at all.

Horiba Laqua Twin N

The Laqua twin device is the only device that gives an actual level of NO_3 in the leaf tissue. In the laboratory tissue analysis total N (NO_3 + NH_4) is tested, so the figures are not directly related between the leaf tissue analysis and the device output. Tissue analysis also includes protein nitrogen present in the cell which is added in to the total N figure. Therefore the tissue N levels are higher than the equipment readings. The difficulty of obtaining adequate sap for testing is a challenge with *Chamaecyparis*, *Buddleja* and *Viburnum*. However the fleshy leaves of *Tradescanthia* yielded adequate sap volume. Differences between sites was evident in the statistical analysis with a highly significant p value ($p < 0.05$) for Viburnum, Tradescanthia, Chamaecyparis and Buddleja. The device whilst reflecting N tissue levels well is impractical for general nursery use.

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 5 samples)

(4) Readings should be made in the shade to avoid direct sunlight affecting the meter.

Leaching

Whilst this trial did not set out to research leaching information it was recorded and showed some interesting points. During the trial there was a high initial N release, which was not expected. This then decreases once the nitrogen in the base fertilizer and Urea has been consumed. There are considerable differences in the nitrogen uptake between the plants,

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

both initially and during the season's growth. Figures 18-20 show the level of nutrients in the pour-thru water at intervals during the season expressed as NO_3-N/m^2.

Viburnum requires very little early nutrient levels and data suggests that the optimum CRF level would be 4kg/m³, compared with the high levels of leached nutrients in the 6 and 8kg/m³ treatment. This crop would benefit from a slow start CRF, see Figure 18.

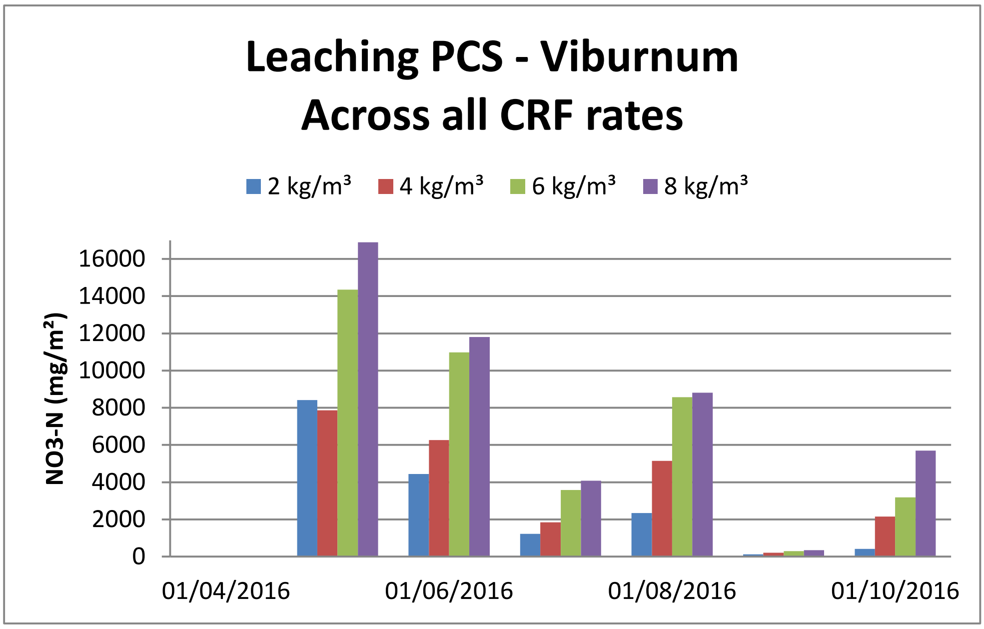

Figure 18 shows the level of nutrients leached for *Viburnum* at PCS

Tradescanthia is a gross feeder and the data shows that it consumes far more of the nitrogen that the other subjects, supplied to the crop, even at 8kg/m³, see Figure 19. Once the root system was established and the plant actively metabolising nutrients, the leaching reduced down to very low levels. However the plant quality at the higher Osmocote rates was not at a marketable standard.

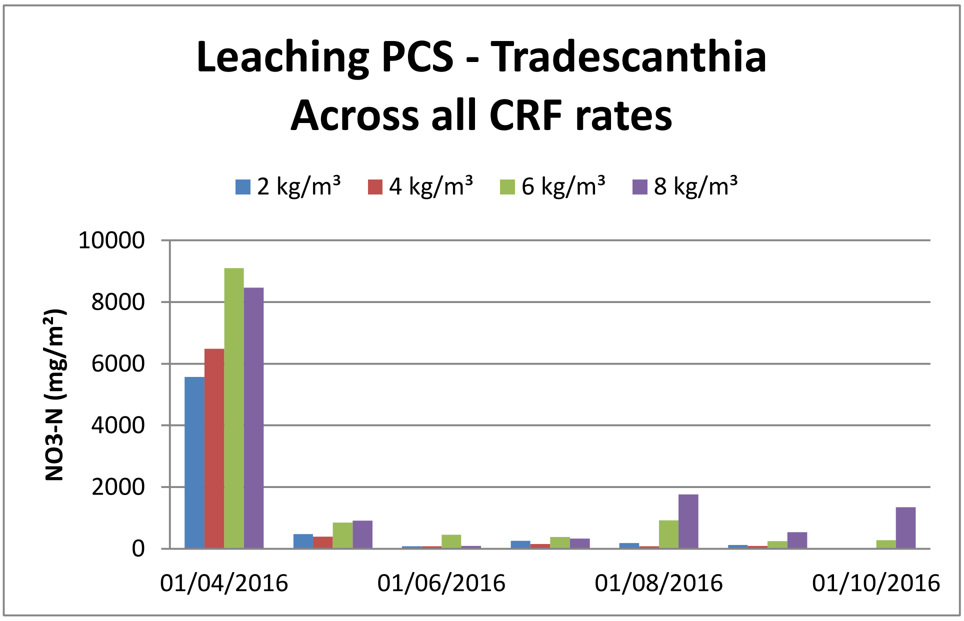

Figure 19 shows the level of nutrients leached for *Tradescanthia* at PCS

Buddleja is similar in response to *Tradescanthia*. It is a fast growing shrub that quickly utilises the nutrients in the pot once the root system is established. When the plant growth became too high for the pot size they were trimmed. Again, as in year 1, a small spike of high nutrient leaching occurred after trimming, see Figure 20.

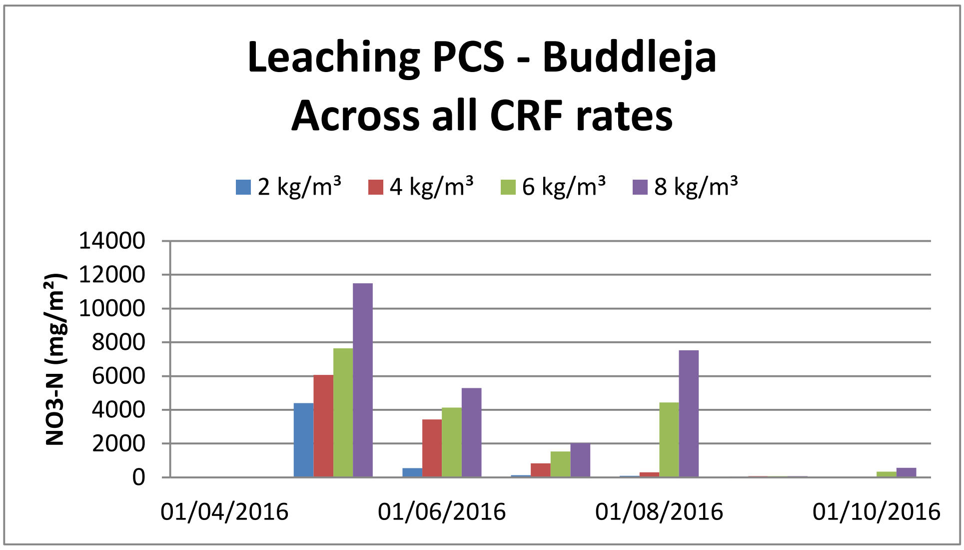

Figure 20 shows the level of nutrients leached for *Buddleja* at PCS

By way of comparison to year 1, Figure 21 shows the fate of nitrogen in a pot for a *Buddleja*. It should be noted that the tissue N levels relate to total nitrogen and includes any protein nitrogen, whereas the leachate and substrate refer to nitrate and ammoniacal nitrogen

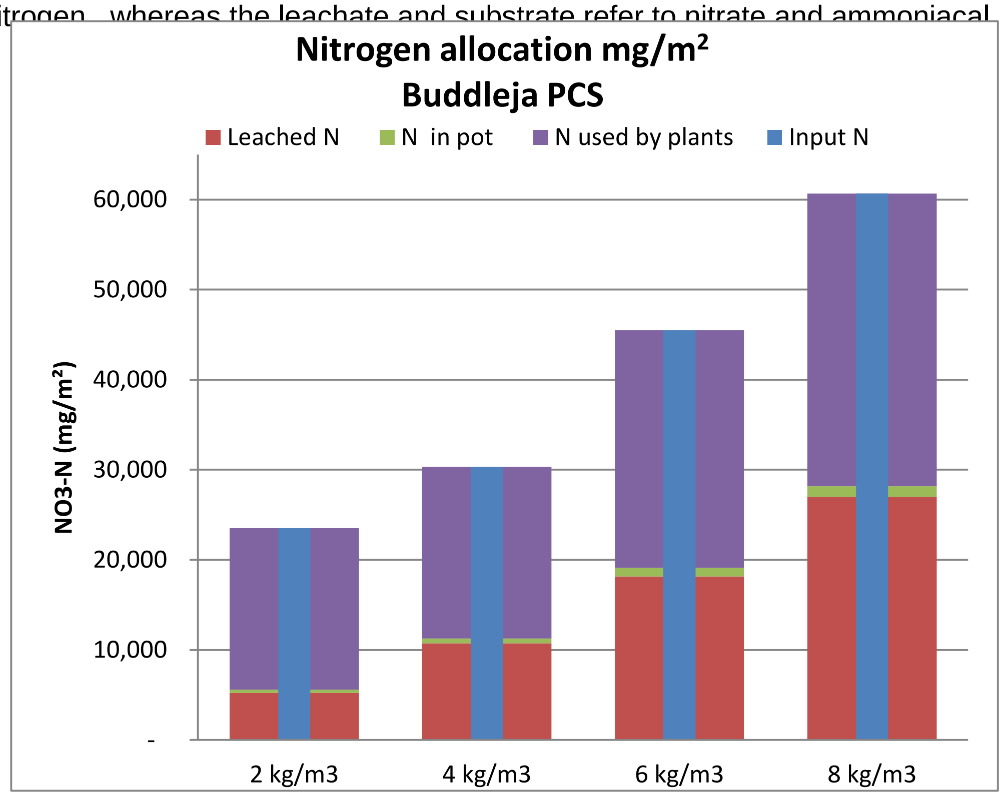

Figure 21 shows the distribution of Nitrogen for *Buddleja* at PCS

Discussion

The aim of this project is to examine the possibility for growers to make use of on-nursery tools/equipment to gauge the nutritional status of plants, without having to resort to destructive sampling and sending of samples to laboratories for analysis. The latter is seen as relatively expensive and is generally only done if there appears to be a problem with the growth of plants, by which time the results may show that recovery is almost impossible in any one growing season.

The work in the second year of the project has shown that doing a real-time sampling of plant material by some of the equipment tested does have potential in giving growers a quantitative record of nutrient status before the eye has the ability to judge differences.

Results have shown that whilst there are differences in the climatic conditions of each of the three sites, the responses of the equipment on test are uniform to each climate.

The challenges brought about by the non-availability of the atLEAF$^+$ device were overcome by purchasing an alternative product that uses a similar same wavelength light measurements but at four times the cost. In response, growers were very pragmatic about this and accepted that if it could prevent a crop failure then the cost was justifiable.

The necessary pre-treatment of the plant material to obtain sap for the Horiba Laquatwin is not a suitable process for nurseries to carry out in general. The equipment will not be continued in year 3. The extraction of sap from nursery stock subjects chosen for the trial was difficult and this would apply to other subjects if there was more widespread adoption of the product.

The relationship of equipment output to leaf tissue levels is variable between species and this trial is showing that to produce a “blue print” for a range on nursery stock subjects would be an extensive task. However, what the trial does show is that “one-size” does not fit all subjects if the levels of leaching are to be controlled. Consideration should be given again to the use of CRF incorporation by “dibbling” to enable more accurate levels of nutrient application, linked to plant need. The leached levels from the *Buddleja* were much higher than the *Tradescanthia*, and the uptake pattern for *Viburnum* was quite different to the other plants. The ability to switch the different CRF release patterns and longevity for different plant types would be needed to achieve a better control over leaching levels.

The leaf tissue tests also show a decreasing level of N over the growing season. This may indicate that the early release of nutrients means the CRF is unable to provide the nutrients the crop requires towards the end of the season. This situation may not be problematic in reality, as the crop would be sold as soon as it was mature and planted in a garden before the CRF levels were depleted. In this trial some of the subjects were grown beyond the normal saleable stage.

There are several practical points for a grower using equipment that help in understanding the results.

- Some husbandry work can affect substrate EC levels and nutrient uptake.
- Clear labelling of tissue samples so that accurate identification can be made even if they don't come back from the laboratory in same order as sent.
- More frequent sampling (e.g fortnightly, or at regular intervals) is necessary in the first year, so that trends can be developed even if tissue samples get lost or damaged.

We have established that similar trials have been carried out in Germany[2] on two tree subjects. We have received their annual report and have found the relationship between chlorophyll colour and nutrients that correspond with this project.

Conclusions

- Sap measuring devices are impractical on nursery stock subjects
- Chlorophyll measuring devices can provide an indication of nitrogen levels in the tissue this reduces as senescence increases through the season.
- Substrate levels of controlled release fertilizer (CRF) need to be regulated to reduce levels of leached nutrients. 'One size' does not fit all. Plants need to be categorised into feeding level groups.
- For early spring growth the chlorophyll measuring systems can detect reducing nitrogen levels in plant leaf tissue before it is detectable by eye when using LED technology.
- The CRF levels of nutrients that decrease over the season is in part due to excessive release after potting.
- The use of Urea in place of Calcium ammonium nitrate or Nitro Chalk will reduce the high initial substrate conductivity levels.

[2] Eignung verschiedner, Schnelltestverfahren zur Ermittlung des Nahrstoffgehaltes in Pflanzensaften von Gerholzen. *Marie-Luise Schachtschneider*, Vub Ellerhoop Jahresbericht 2016. Pgs 56-61

- The choice of *Tradescanthia* as a test plant subject in place of *Skimmia* was a wise decision. Being a gross feeder it gave good growth, colour, leaching and tissue responses.
- More frequent measurements will be taken in year 3 with the chlorophyll and conductivity systems to increase the level of statistical outputs from the data.
- The levels of ambient light prior to taking leaf chlorophyll readings do not affect the readings.

Knowledge and Technology Transfer

Two workshops were carried out in the winter of 2016, one in the north and one in central England, which were well attended. Details of the results from year 2 were presented and the event included presentations from projects with nutritional aspects that complimented this project. Delegates were given the opportunity to try out the equipment on test.

For the technology transfer in 2017 we will be taking a stand at the Four Oaks trade show where we will be able to dialogue with a greater number of growers than a workshop. We will demonstrate some of the equipment and this will be followed by input at the CP138 Growing media workshop in September and the "Masterclass on nutrition" workshop being arranged by AHDB, prior to GroShow.

Appendices

Further data sets for equipment, site, and species is available on request to John Adlam, john@dovebugs.co.uk.

Appendix 1 – Weather data Figures 22-25

All the sites each collect weather data on a half hourly basis. The data recorded for the trial purposes are average daily air temperature, rainfall and W/m². The comparisons between all of the sites is shown in the following four charts.

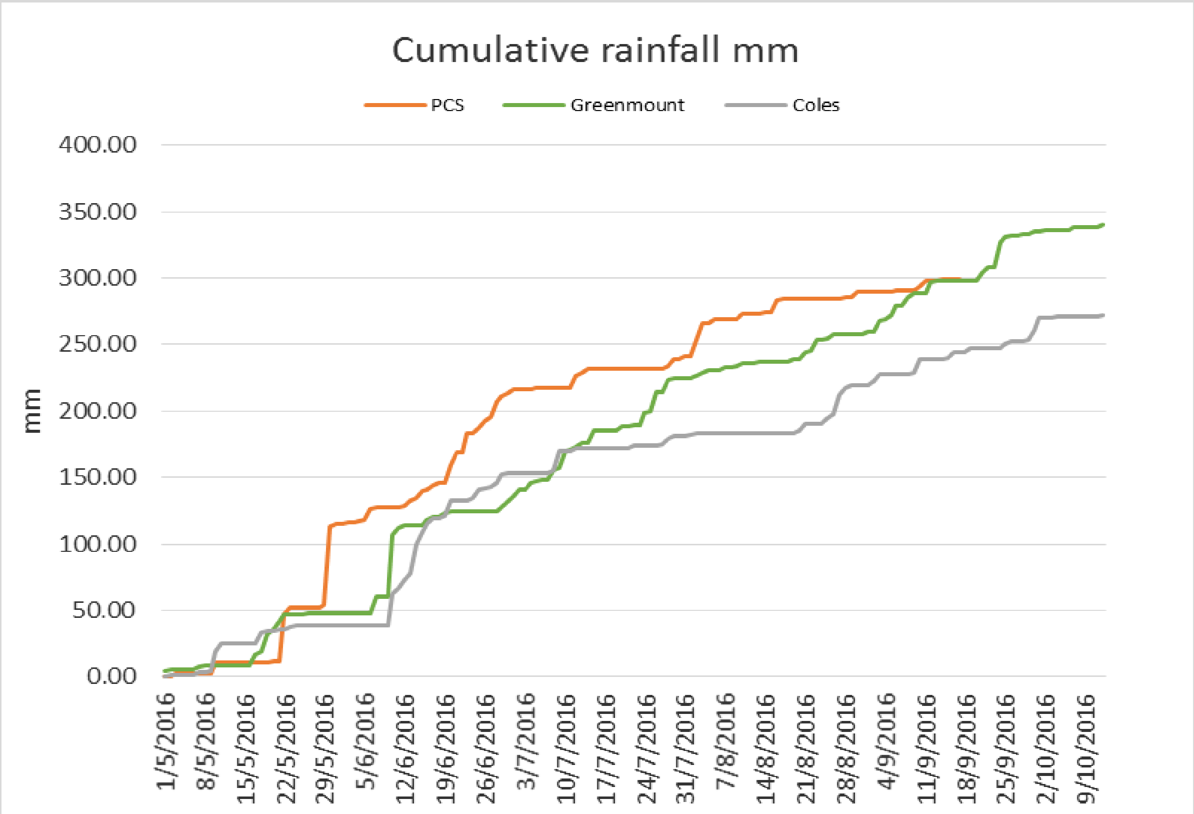

Figure 22 shows cumulative rainfall across all 3 sites

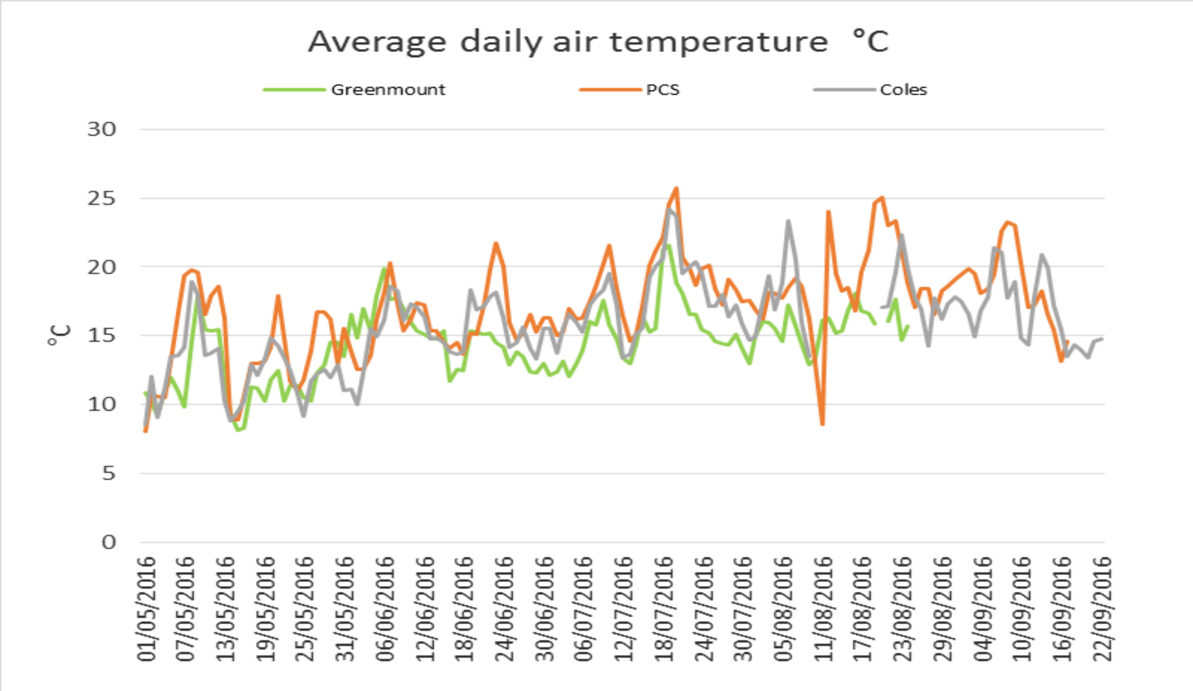

Figure 23 shows the average daily air temperatures across all 3 sites

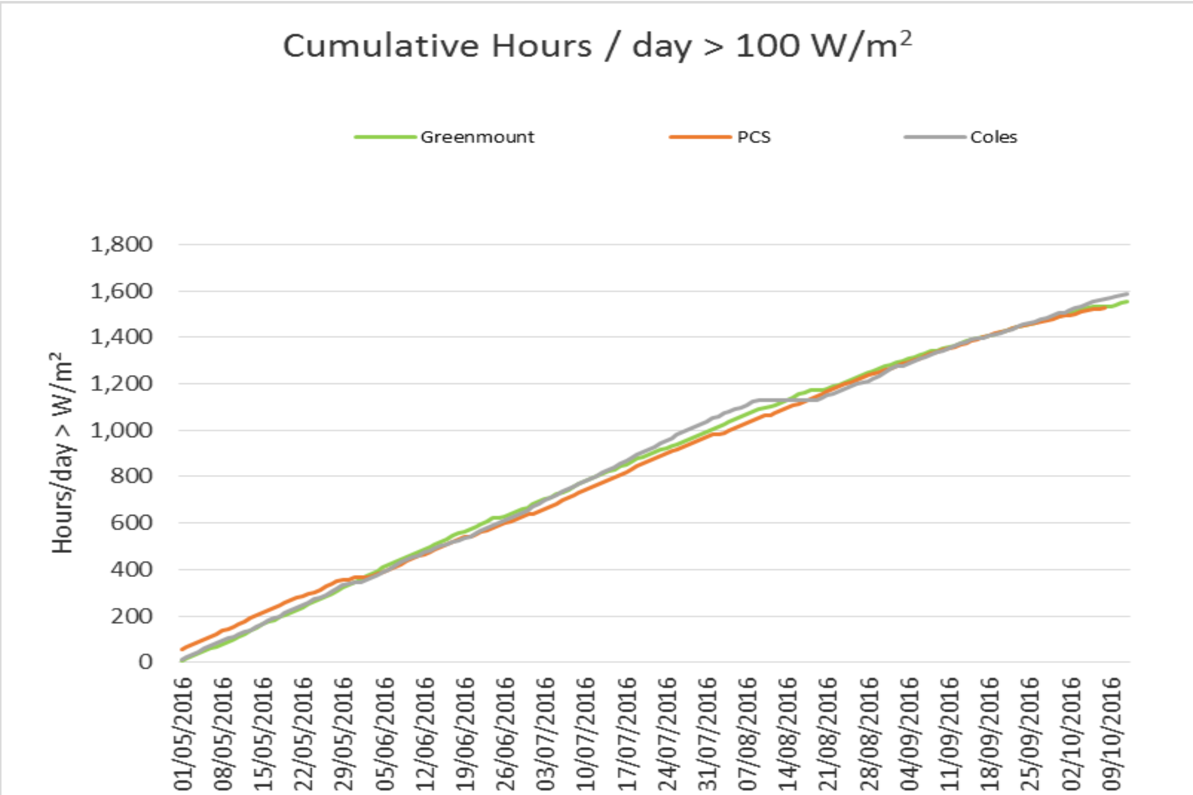

Figure 24 shows the cumulative hours per day >100w/m² across all 3 sites

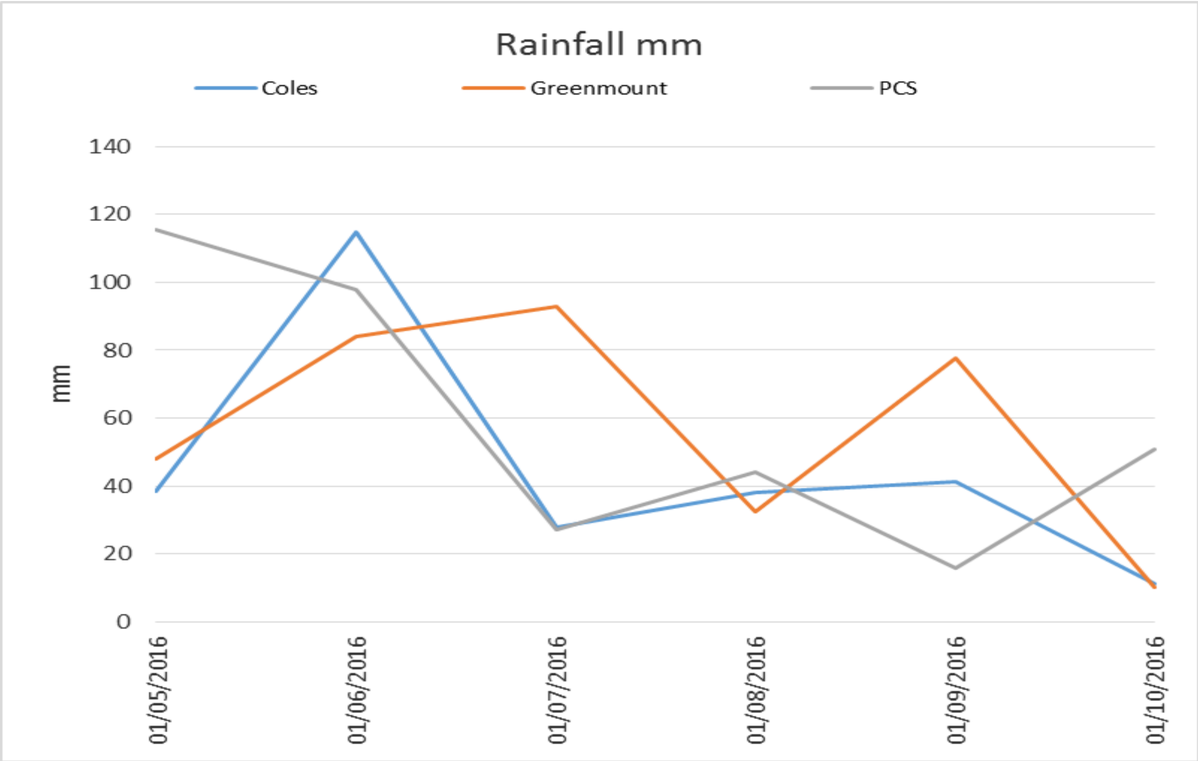

Figure 25 shows the total rainfall across all 3 sites