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Key staff:	Hilary Papworth Benjamin Tea
Location of project:	Cambridge
Industry Representative:	
Date project commenced:	01/09/2018

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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

Using best practice growing methods is as important as the type of feed applied; monitoring growing media and water, as well as plant growth are vital in avoiding nutrient deficiency, toxicity, and unnecessary waste of feeds.

Application of liquid feed through overhead irrigation has the benefit of foliar uptake of nutrients but in periods of low water use, better results are achieved with a controlled release fertiliser (CRF).

Financial savings can be made using capillary matting as part of the irrigation system but monitor for unwanted salts.

Marginal leaf necrosis in primula has multiple causes, but calcium (Ca) nutrition can be improved by adapting the growing environment and application of foliar calcium nitrate ($Ca(NO_3)_2$).

Application of nitrogen (N) to field grown narcissus at leaf emergence has no benefit over later application.

Application of N at a rate of 80 kg/ha increases harvest bulb weight in field grown narcissus but does not increase incidence of basal rot (*Fusarium oxysporum* f.sp. *narcissi* (FON)). Application of N at rates of 50 kg/ha or lower have no impact on harvest bulb weight.

Background

The target of this project is to make nutritional recommendations for key crops in the protected ornamental, bulb and outdoor cut flower industry which could form part of the guidance available in RB209. When making nutritional recommendations it is important to understand the nutritional requirements of the plants and also how the different variables in the production system will alter the availability of different nutrients.

A key area of investigation was to see how peat-reduced growing media mixes containing different components interacted with liquid feed applied via different irrigation methods, and to different crops at different times of year. The aim was to provide best practice advice on the use of liquid feed in protected ornamental crops, and how to make changes in feed regimes in response to changes in growing media as peat is phased out of use.

Specific nutrient problems were identified in the project outline and in the scoping study; investigations were undertaken to improve primula nutrition for avoidance of leaf edge scorch and to tackle iron (Fe) deficiency in pH sensitive crops.

In a 3 year study on N nutrition in field-grown narcissus carried out at the trial sites in Cornwall and Lincolnshire, the aim was to review the current advice available in RB209 and to also look at the potential link between N application and incidence of basal rot.

Summary

Experimental investigations were carried out over a 4-year period, with trials undertaken at NIAB's Cambridge site for glasshouse work, and in Lincolnshire and Cornwall for the field-based narcissus trials. In Cambridge a bespoke set up of tabletop benches and irrigations systems were used to compare liquid feed application to bedding crops through different irrigation methods, a total of 5 trials were completed. The trial compared the results for plants grown in peat reduced growing medias, which were 70:30 peat perlite mix, 70:30 peat wood fibre mix, and 70:30 peat coir mix. A standard balanced feed was used, this was OMEX Adjust range, O-Mix 21-7-21 + 1.6 MgO + TE. In trials growing pansy in autumn/winter, the liquid feed was compared with a CRF with NPK ratio of 12-7-18 + TE, and a release time of 2 to 3 months (Osmocote Bloom), at a rate of 3 g per l.

Monitoring was carried out on growing media pH and electrical conductivity (EC) by saturated media extraction (SME), irrigation water and run off pH and EC, and nutrient content of growing media and leaf tissue by laboratory analysis.

The trial results showed that in spring/summer where water use was high, the 3 irrigation systems investigated (ebb and flow, overhead and drip irrigation with capillary matting) all produced a saleable crop. Plants grown under the ebb and flow irrigation system had the highest fresh weight, except where the growing media mix contained 30% wood fibre.

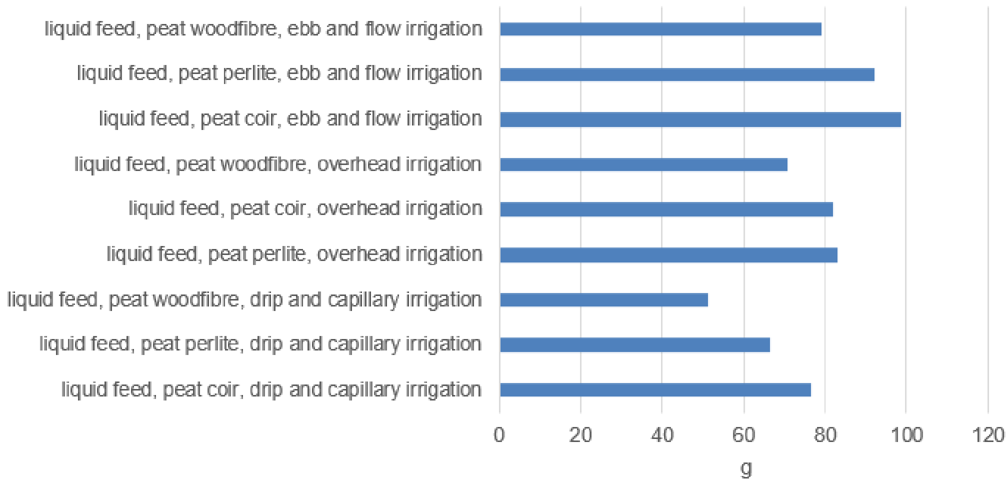

Figure 1. Results for spring/summer trial of petunia showing fresh weight (g) of above ground growth observations dated 07/08/2019.

Use of overhead irrigation proved very effective where water use was moderate to high, and in some trials this produced a fresh weight that was equal or higher than those grown with

ebb and flow irrigation. As the feed concentration is the same this is likely a result of the added action as a foliar feed. As overhead irrigation used less water in the trials than ebb and flow, this can be regarded as more efficient use of water and feed.

Use of overhead irrigation with hard water did result in the greatest increases in growing media pH over the duration of the trial, which is a concern for pH sensitive crops and resulted in bicarbonate induced chlorosis in petunia.

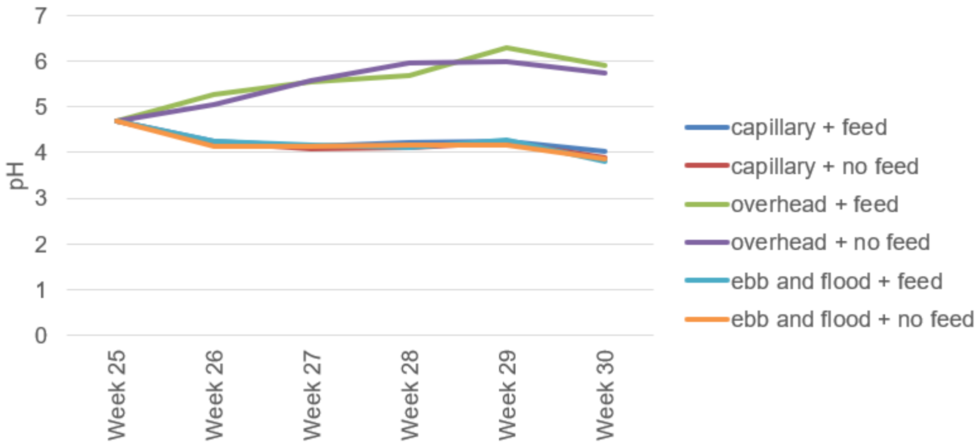

Figure 2. pH over duration of trial in peat and coir mix growing media treatments, from spring/summer trial of petunia 2019 trial.

In the winter where water use was very low, moving from liquid feed to a CRF produced the highest fresh weight. This was the case even when using an irrigation system with capillary matting with which liquid feed produced very low weight plants.

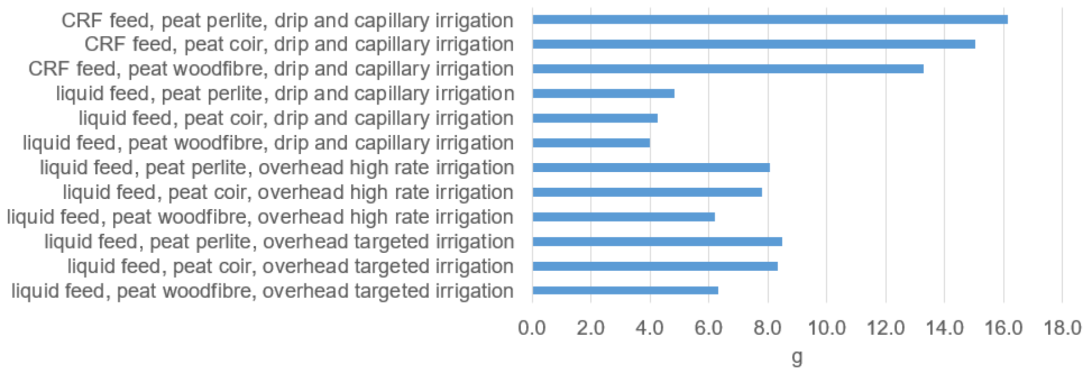

Figure 3. Results for winter trial of pansy showing fresh weight of above ground growth displayed according to irrigation method and ranked for weight (g), observations dated 06/01/2022.

The results in figure 3 also show that when watering was increased in the overhead irrigation (high rate vs targeted), there was no positive effect. Demonstrating that if plants do not require additional water, they will not take up additional liquid feed. Increasing the feed:water ratio is a better option, which will help to avoid waterlogging and anaerobic growing media conditions.

Results showed that with 70% peat and 30% wood fibre growing media mix, plants had the lowest fresh weight in every combination of feed and irrigation, indicating that mixes high in this substrate would benefit from an increased concentration of feed. The growing media mixes containing 30% coir had consistently higher potassium (K) levels, due to properties of the substrate. Mixes high in coir should be checked for high levels of K and choose a feed which accounts for this to avoid inhibition of N and Ca uptake.

Investigations into leaf edge scorch in primula indicated that there are multiple causes of leaf necrotic tissue. Work over 4 trials at NIAB and a comparison with a commercial nursery indicate that causes can be diverse, as shown in figure 4.

Figure 4. Comparison of different possible causes of necrotic leaf margins, (from left to right) potential nutrient toxicity (possibly Na), thermal stress and potential nutrient deficiency (Ca).

Nutrition can be improved by altering environmental factors that affect movement of Ca in the plant, such as reducing humidity at crop leaf height, or avoiding water stress which also has the benefit of reducing the risk of thermal stress. Leaf necrosis in both cases is related to problems with lack of transpiration in the plant.

Ca nutrition was also seen to improve with foliar application of $Ca(NO_3)_2$, but not at rates lower than 1:250 of a compound containing 22.5% Ca, 15% N.

Primula is pH sensitive and prone to bicarbonate induced chlorosis due to Iron (Fe) deficiency, in trial conditions this was reversed by foliar applications of a 2% sequestered Fe product at 5 ml in 1 l water at weekly intervals for 4 weeks.

As growing media pH is a key factor in nutrient availability it was a reoccurring theme in the work. Changing the NH_4 (ammonium) to NO_3 (nitrate) ratio to influence pH is well documented in other studies, and where NH_4 is present as a greater part of the ratio in liquid feeds and base fertilisers it will have an acidifying effect. The opposite effect is seen when NO_3 is greater. For growers transitioning from peat-based growing media to peat-reduced and peat-free mixes, the ability to influence pH using different forms of N could be of increasing relevance. Water retention in peat-reduced and peat-free mixes can be an issue, leading to more frequent or higher volume irrigation. If using water high in bicarbonate (HCO_3^-), the increase in pH seen over time could be greater than using a 100% peat media.

The N nutrition study in field grown narcissus showed that after 2 years of N application, there was an increase in harvested bulb weight with an increase in rate of N, but this was not reflected in stem length or the number of stems produced. The results suggest that the influence from the year (environment), has a greater effect for stem length than N application, and bulb age is a greater factor for number of flowers.

The weight of bulbs harvested at the end of the trial was higher with the application of N at a rate of 80 kg/ha from between 9% and 21% in the varieties tested, but not at lower rates.

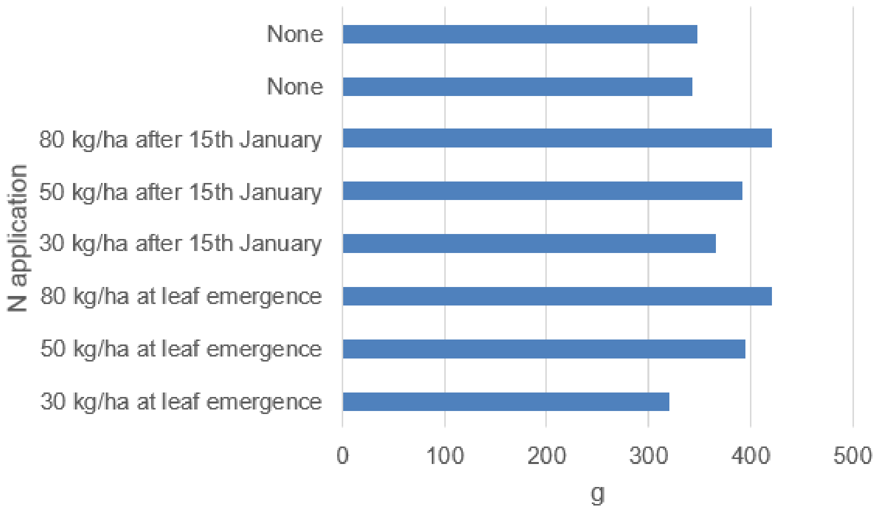

Figure 5. Treatment details and results for weight of harvest bulbs per m from Lincolnshire trial, observations dated 15/06/2022

The results do not support that it would be beneficial for application of N to take place at an earlier stage of the crop, i.e. at leaf emergence when that falls within the Nitrate Vulnerable Zone (NVZ) closed period. No improvement was seen over later application at the same site. This means that N applied during this period where NVZ restrictions do not apply, is likely to be less effective than if it is applied later in the growth stage of the plant.

The study has generated very little data in relation to a link between N fertility and basal rot. Currently there is no evidence to suggest application of N at rates of up to and including 80 kg/ha increased the rate of infection, but this may be a result of the trial design rather than there being no link.

Financial Benefits

By adapting irrigation methods to time of year, savings on fertiliser use can be made. Results indicate that during summer a reduction in fertiliser cost of 44% could be made using capillary matting.

The cost implication of changing from a liquid feed regime to CRF ranges from a 3 fold increase to potentially cost neutral. Cost saving is dependent on the efficiency of the watering system and therefore the amount of liquid feed wasted. Use of liquid feed maybe cheaper, however use of CRF has lower equipment cost and staff time input.

Symptoms of Fe deficiency in primula can be reversed by foliar application of liquid sequestered Fe at a cost of 30 pence* per 1000 plants, saving around 10% of the crop from any deficiency.

Routine Saturated Media Extraction (SME) testing can be completed at minimal cost*, initial outlay for EC/pH Meter – ExTech II - £150 and 2 x 500ml jugs - £10, plus price per test of 20 pence for distilled water and coffee filters.

Save fertiliser costs by avoiding early application of N (at leaf emergence) for field grown narcissus as it has no impact on stem length or flower number.

**Prices are correct as of submission date of report – December 2022.*

Action Points

- In periods of low transpiration be vigilant of overwatering and accumulation of salts (nutrients) in irrigations systems using capillary matting.
- Reduce humidity in the glasshouse to improve Ca content in plants, and avoid water stress (drought) to reduce the risk of scorch symptoms
- Electrical conductivity (EC) is only a method for measuring total ions. Undertake sampling and laboratory testing of irrigation water to get a clear understanding of the amount and type of nutrient ions that are present in the water supply. This can prevent unnecessary fertiliser use and avoid potential nutrient toxicity.
- Regularly monitor the growing media EC to identify both inadequate and excessive levels, particularly in low water use periods.
- Use controlled release fertilisers (CRF) or increase the feed/water ratio for winter crops where irrigation can be low in response to weather conditions.
- In spring and summer Primula crops, reduce humidity in the glasshouse to improve Ca content in plants. This should reduce scorch symptoms.
- Apply N as a top dressing to increase harvested bulb weight at rate of 80 kg/ha but avoid early application as it has no impact.

SCIENCE SECTION

Introduction

The target of this project is to make nutritional recommendations for key crops in the protected ornamental, bulb and outdoor cut flower industry which were planned to form part of the guidance available in RB209. The project was split into different areas of work which were identified in the scoping study described in POBOF 003 year 1 annual report. This identified the key crops, the common problems experienced in those crops and the conditions in which they were most frequently grown.

Outside of the crop specific goals for the project, two other significant aims were identified. Firstly, it was to increase understanding of the impact on plant nutrition when the peat content of growing media is reduced. As reported in year 1, significant work has been carried out on some aspects of crop nutrition with direct relevance to the pot plants and bedding sector (Johnson *et al* 2013). Good understanding on the interaction between plants, substrate and composition of water-soluble fertiliser exists, including some tested models for prediction of effect on substrate pH (Fisher *et al* 2014b). However, much of this work relates to 100% peat based growing media and knowledge needs to be expanded to cope with the changes taking place in response to the UK government aims of net zero carbon emissions. Secondly it was to provide a resource for training, as a knowledge gap was identified during discussions with the industry. There are few resources available to train staff other than formal qualifications such as FACTS or as part of a college horticultural qualification.

A program of work was designed to try and achieve all these aims, this work was carried out over a four-year period; in this final report the areas of study are reported on as separate sections but there are areas of commonality which are drawn together in the grower summary of this report.

During the period of the project the UK and other parts of the world were subject to restrictions in response to the Coronavirus COVID-19 pandemic, this limited opportunities for in person meeting, Knowledge Exchange (KE) and nursery-based trials. Before restrictions were lifted the industry had voted to end the levy funding AHDB activities which has further limited the KE opportunities for this work, and the opportunities for project work to further explore the findings.

Introduction – Section 1. Interactions between irrigation type, growing media type and pot size with relation to the delivery of liquid feed to different plant species

In this section of the project, work was carried out examining the interaction of irrigation, liquid feed and peat reduced growing media mixes. In the peat reduced growing media mixes, 3 different types of alternative materials with different properties were used, with the rate of replacement material used at 30% of the overall mix. In the move to meet government targets for net zero carbon emissions, and the goal of parts of the industry to be more environmentally sustainable, growing media is moving to a minimum of 40% peat replacement and entirely peat free professional mixes are more common. During this project the requirements for peat-free growing media have moved on and deadline for a UK ban on retail peat growing media is confirmed for 2024, and for the professional user this is expected for 2028 - 2030. By looking at three components with different chemical properties it is hoped that understanding of the interactions between them and water-soluble fertiliser can be developed to support the industry in this move.

However, it is important to note that the source of components and processing methods has changed over the period of the project, and that is expected to continue as the growing media industry evolves their products. Wood fibre, coir and peat will have changed source and/or processing method, and this will have to some extent changed the properties of the growing media that is made from them. This could include ability to retain water, buffering capacity, natural content of ions and biological activity; all of these will impact in the requirement for application of nutrition for the plants that are grown in them. The project is reflecting the situation that growers themselves face and will continue to face in the coming years as all peat is phased out from use, and growing media manufactures develop mixes with new components to meet industry demand for the peat-free product. This highlights the need for understanding of the properties of the media and the interaction with irrigation and nutrient, as well as the necessity of regular monitoring and testing by the grower.

A total of 5 trials were carried out in the period from 2019 to 2022. The work on the 2 trials carried out in 2019 is described in the document POBOF 003 annual report 2019, and the work on the 2 trials completed in 2020 is described in the document POBOF 003 annual report 2020.

In the final year of the experimental work, investigations continued into the most effective route for application of liquid feed into bedding crops grown under protected environments, with the addition of further investigation into the use of controlled release fertilisers (CRFs) as an alternative method of nutrient delivery.

Materials and methods

In autumn/winter 2021 to 2022 an investigation was undertaken to see if the results obtained in the same period in 2020 were repeated. The trial was grown in a glasshouse at NIAB's Cambridge trial site. The glasshouse was set to maintain a minimum temperature of 10^{o}C, no supplementary lighting was provided, and no shade screens were utilised. The trial was carried out on a tabletop bench fitted with Stal & Plast liners. Each table was L 383cm x W 63cm x H 75cm with its own individual irrigation method incorporated.

The test plant was Pansy 'Carneval® Yellow with Blotch', these were obtained from Volmary as plug plants and were received on 04/10/2021. On 05/11/2021 the plugs were transplanted into H. Smith Plastic 12 cell bedding pack. (D – 23.0 cm, W – 17.5 cm, H – 6.5 cm, Volume: 0.104 lt.) using three different peat reduced growing media mixes. The mixes were 70:30 peat and perlite mix, 70:30 peat and wood fibre mix and 70:30 peat and coir mix.

No wetter or base feed was incorporated into the substrate, and the pH was adjusted to between 5.5 – 6. The peat used was the same for all mixes and was 0-10mm grade, the perlite was 0-6mm grade.

The irrigation was applied by 2 different methods, either overhead manual irrigation or drip irrigation with capillary matting. The overhead irrigation was applied at 2 different rates to see if there was any difference between the plants produced under a high water rate or the more targeted manual irrigation as used in 2019 and 2020 trials.

Irrigation events were determined by the requirements of the plants and all systems were allowed to drain freely following irrigation events, with no water recycling. The water supply used was mains supply for the area (hard water) with no other treatment.

Table 1. Results of chemical analysis for the irrigation water at the Cambridge site.

	*		mg/l																µg/l
Sample	pH	EC µS/cm	nitrate N	SO4	B	CU	Mn	Zn	Fe	Cl	P	K	Mg	Ca	Na	Carbonate	hardness as CaCO3	Alkalinity as HCO3	dissolved Mo
Glasshouse irrigation water	7.7	611	9.8	30.8	0.03	<0.01	<0.01	<0.01	<0.01	39	0.8	2.7	3.74	116.6	16.7	<10	306.5	277	0.31

***pH and conductivity measurements made at 20 ^{o}C.**

The trial contained 2 different feed regimes, these were the same as used in the 2020 trials.

The feeds used in the different treatments were as follows:

1) A liquid feed (L) from the OMEX Adjust range, O-Mix 21-7-21 + 1.6 MgO + TE which was made up to a stock solution of 1 kg/10 l which was diluted 1:200 using a Dosotron

D3 Green Line injector. The resulting feed supplied 105 ppm of N in the form of 1.6% NH_4 N, 3.4% NO_3 N, 16% Ureic N.

2) A controlled release fertiliser (CRF) with NPK ratio of 12-7-18 + TE, and a release time of 2 to 3 months (Osmocote Bloom), incorporated at a rate of 3 g per l of growing media. As no base feed is present in the growing media an initial liquid feed will be applied to provide nutrition while the product activated.

Table 2. Abbreviation codes used in data collection and statistical analysis.

Variable	Code	Types
Feed	L	Liquid
	CRF	Controlled release fertiliser
Irrigation type code	IAi	Manual Overhead – targeted watering (6-8 l per irrigation event)
	IAii	Manual Overhead – high rate watering (10-12 l per irrigation event)
	IC	Capillary with trickle tape
Growing media type code	SA	Peat and perlite mix
	SB	Peat and wood fibre mix
	SC	Peat and coir mix

Table 3. Treatment descriptions and codes used in the trial.

Bench no.	3	3	3	4	4	4	1	1	1	2	2	2
Treatment no.	1	2	3	4	5	6	7	8	9	10	11	12
Feed	L	L	L	L	L	L	L	L	L	CRF	CRF	CRF
Irrigation code	IAi	IAi	IAi	IAii	IAii	IAii	IC	IC	IC	IC	IC	IC
Substrate code	SA	SB	SC	SA	SB	SC	SA	SB	SC	SA	SB	SC

The trial contains 12 treatments arranged on 4 benches arranged in a split split plot design, with 6 cell packs (each containing 12 plants) per treatment per species.

Assessments were made 9 weeks after potting, this consisted of plant height measured in centimetres (cm), a count of the number of flowers and the fresh weight of the above ground growth in grams (g), along with photographs of plant and roots from each of the treatments.

The data from the trial was statistically analysed using analysis of variance (ANOVA) in order to determine the difference between treatments.

Weekly observations on growing media electrical conductivity (EC) and pH were made from saturated media extraction (SME) using EXTECH ExStik II meter.

A sample of plant tissue and growing media from each treatment was also sent for laboratory analysis at the end of the trial. The material sent was a bulk sample taken from at least 10 randomly selected plants.

Results

In previous years the results for fresh weight proved to be the most illustrative indicator of performance so these have been used again in 2022 to illustrate the outcome of the trial. See Tables 1, 2 and 3, in Appendix 1 for all plant observations and statistical analysis.

The significant difference quoted have been seen at 95% confidence interval.

Table 4. Results of plant observations dated 06/01/2022.

Feed code	L	L	L	L	L	L	L	L	L	CRF	CRF	CRF
Growing media type code	SA	SB	SC	SA	SB	SC	SA	SB	SC	SA	SB	SC
Irrigation type code	IAi	IAi	IAi	IAii	IAii	IAii	IC	IC	IC	IC	IC	IC
Treatment no.	1	2	3	4	5	6	7	8	9	10	11	12
Average results for plant observations												
Height (cm) (L.S.D. 0.6866)	4.6	3.7	4.3	4.6	4.1	3.8	3.9	3.6	3.6	6.8	6.4	6.9
Number of flowers (L.S.D 1.525)	1.2	0.8	1.5	1.5	0.3	1.2	0.3	0.2	0.2	6.3	5.0	5.7
Fresh weight of above ground growth (g) (L.S.D 1.601)	8.5	6.3	8.3	8.1	6.2	7.8	4.8	4.0	4.3	16.1	13.3	15.0

For plant height no significant difference was observed between treatments 2, 6, 7, 8, and 9. Treatments 1, 3, and 4 are significantly taller than the observation for the smallest treatments. All treatments grown using CRF are significantly taller than those grown with liquid feed, irrespective of the other variables in the trial. No significant difference was observed between the different growing media mixes where the CRF is used.

No significant difference was observed between treatments 1 to 9 in the number of flowers. Treatments grown using CRF all have significantly more flowers than those fed with liquid feed. As with plant height no significant difference was observed between the different growing media mixes where the CRF is used.

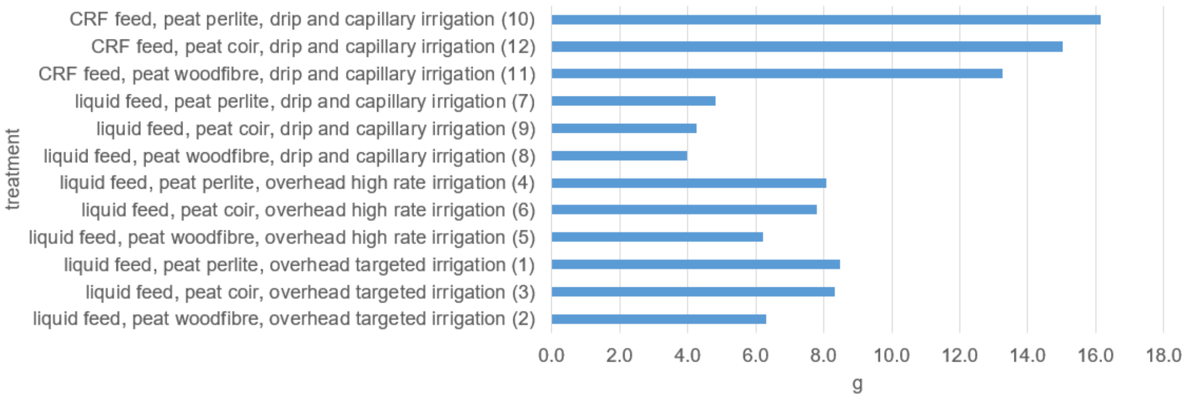

Figure 1. Results for fresh weight of above ground growth displayed according to irrigation method and ranked for weight (g).

The lowest fresh weights are observed in the treatments with drip irrigation and capillary matting with liquid feed, and the highest in the drip irrigation and capillary matting with CRF. When comparing the two overhead irrigation benches, those that were watered in a targeted manner are slightly heavier than those with the higher rate watering regime, however the difference between the plants grown under the 2 rates is not significant in this respect. Within the different watering and feed regimes there are significant differences between the growing media types. With both overhead irrigation and the drip, and capillary with CRF, the growing media blend with wood fibre gives a significantly lower fresh weight than peat and coir, or peat and perlite. There is no significant difference between the fresh weight for the plants grown in the peat and coir, or peat and perlite mixes within the combinations of feed and irrigation method.

The results for higher fresh weight with CRF are reflected also in the results for the leaf tissue analysis, the highest values for total nitrogen (N) in leaf tissue is seen where CRF is used with the impact greater for nitrate (NO_3) form than ammoniacal (NH_4) form. The growing media analysis shows the greater availability of N in these treatments.

Table 5. Results of leaf tissue (SAP) and growing media analysis for NH_4, NO_3, phosphorus (P) and potassium (K), samples dated 06/01/2022.

Feed code	L	L	L	L	L	L	L	L	L	CRF	CRF	CRF
Growing media type code	SA	SB	SC	SA	SB	SC	SA	SB	SC	SA	SB	SC
Irrigation type code	IAi	IAi	IAi	IAii	IAii	IAii	IC	IC	IC	IC	IC	IC
Treatment no.	1	2	3	4	5	6	7	8	9	10	11	12
Leaf tissue analysis (results in mg/l)												
NH4	43.5	8.3	47.3	45.5	39.3	42.9	28.3	29.5	32.0	55.4	47.2	45.7
NO3	6.7	26.8	67.7	7.5	0.9	7.2	4.1	3.2	1.2	339.7	141.4	224.1
P	457	470	662	443	365	621	153	217	372	477	339	439
K	3597	4736	5299	3609	4099	5347	3670	4265	5073	5338	4785	5343
Growing media analysis												
pH	5.3	5	5.9	5.3	4.9	6	5.2	4.9	5.7	4.8	4.5	5.1
EC @20c (µS/cm)	36	39	70	29	34	61	58	49	112	265	255	276
Total sol N (mg/l)	2.8	2	2	1.8	1.5	1.7	1.6	1.5	1.9	40.3	35	34.9
P (mg/l)	0	0	0	0	0	0	0	0	1	5.6	4	5.2
K (mg/l)	3	3.3	54	2	2.6	41.6	3.8	2.9	80	59	52.8	153.1

The full results of the leaf tissue and growing media analysis can be found in Tables 1 and 2 in Appendix 2.

In the leaf tissue analysis, the results for K are highest in the peat coir mixes, or where CRF is used. The lowest levels are observed in the peat and perlite growing media mix and with the liquid feed. P levels have been less obviously affected by the form of feed used, it is lowest in the drip irrigation with capillary matting and liquid feed combination, the images below in Figure 2 show purpling of leaves in these treatments which is associated with the symptoms of P deficiency. In pansy, purple margins can also be a symptom of zinc (Zn) deficiency, however in this instance the results of the leaf tissue analysis show treatments 7, 8, and 9 to have values for Zn within the range of all other treatments.

		
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9
		
Treatment 10	Treatment 11	Treatment12

Figure 2. Images of plants at final assessment, dated 06/01/2022.

Further images from the trial can be found in Appendix 3 of the report.

The leaf tissue analysis also shows high magnesium (Mg) and calcium (Ca) in the perlite mixes, the cause for this is not entirely clear.

We also observed very high levels of leaf tissue sodium (Na) compared with previous year, in general terms these were x10 of the 2021 results. The increase was particularly high in the combination of drip irrigation and capillary matting with liquid feed. The experimental design does not give an obvious source of the high levels, but it is possible that these contribute to the poor plant growth.

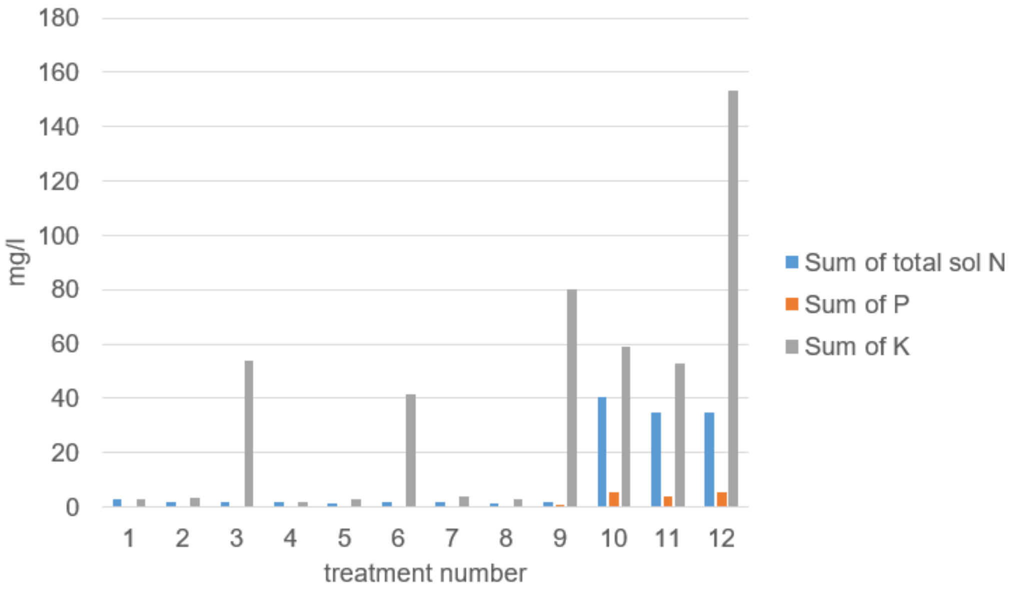

Figure 3. Results of growing media analysis for N, P, and K (mg/l) from samples dated 06/01/2022.

The results for growing media analysis show that the highest EC and total soluble N are found in the treatments that contain CRF.

Within each of the different combinations of irrigation and feed regime, the peat coir mix has the highest EC, with little difference between peat and wood fibre and peat and perlite mixes. Treatment 9 the capillary irrigation, liquid feed and peat and coir mixture has the highest EC of the non-CRF treatments, but the plant material is very small with the second lowest fresh weight. In this treatment high levels of chloride (Cl) in the growing media maybe contributing to the high EC, potentially accumulated due to the irrigation method. This also demonstrates that the level of EC is not a good indicator of nutrient availability when used on its own. The levels of P are also highest in treatments grown with CRF feed, in other treatments there are negligible amount of P available in the growing media at this stage, but this has had no observable impact in the levels in the leaf tissue. The results for K are highest in the treatments with peat and coir growing media mixes even when no CRF is used, this mirrors the leaf tissue analysis results.

The laboratory analysis results show that all treatments have growing media pH values at 6 or below. All pH values for wood fibre mixes are below 5 which are the lowest values observed for the different growing media mixes. For each of the irrigation and feed treatment combinations the highest values are seen in the peat and coir mixes, and the lowest in the peat and wood fibre mixes.

When looking at the pH values obtained by SME during the trial the pH follows the same pattern for each growing media under the different combination of irrigation method and feed regimes, with the coir mix having the highest pH, followed by perlite and lowest is wood fibre. This order is not the same as seen in previous years.

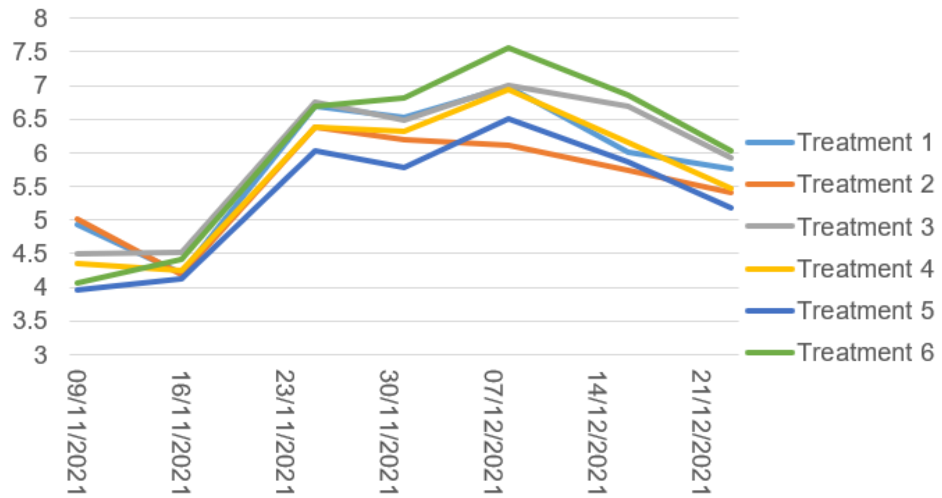

Figure 4. Observations for growing media pH obtained by SME for treatments grown with overhead irrigation.

Full results of the pH and EC values obtained by SME can be found in Tables 3 and 4, Appendix 2 of the report.

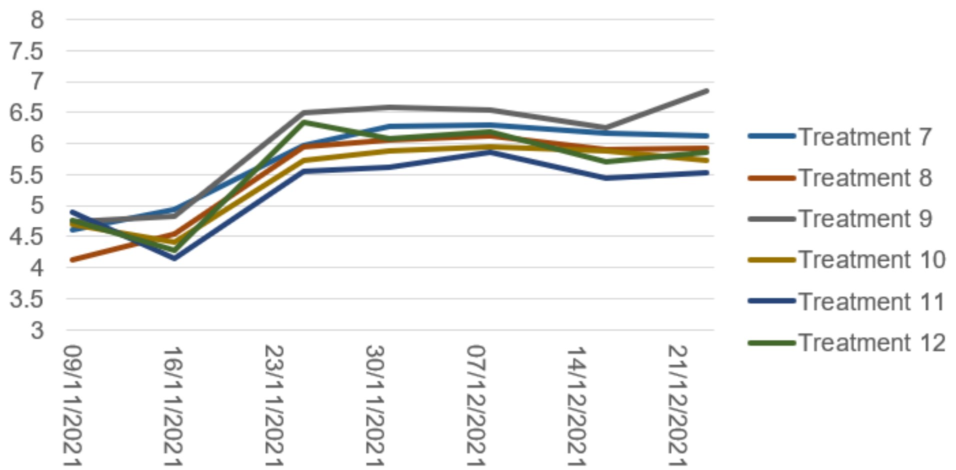

Figure 5. Observations for growing media pH obtained by SME for treatments grown with drip irrigation and capillary matting.

The trend for growing media pH is for it to rise over the duration of the trial, all treatments have higher final pH compared with the starting value. The highest values are seen in samples dated 08/12/2022, 5 weeks after potting, where treatments with overhead irrigation have the highest values. Highest value overall was seen in treatment 6, followed by 3, both are coir mixes with overhead irrigation.

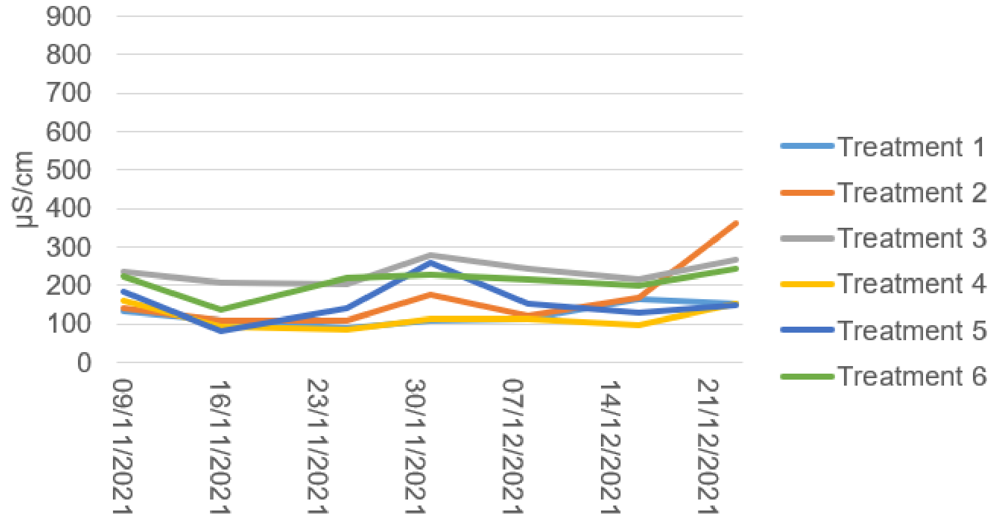

Figure 6. Observations for growing media EC obtained by SME for treatments grown with overhead irrigation.

The EC value for the growing media obtained during the trial show that all treatments receiving liquid feed through overhead irrigation had stable but low EC. The EC for the treatments with growing media mix with peat and coir were higher, but this is as expected as the starting EC of this mix was higher due to the properties of the coir, than the peat and perlite mix, and the peat and wood fibre mix.

The results show that there was no positive impact on the level of EC from the additional water rate and consequently greater quantity of feed. When considering the final EC of the same growing media mixes under the 2 watering regimes, those under the higher watering rate have a lower or equal EC compared with the targeted watering.

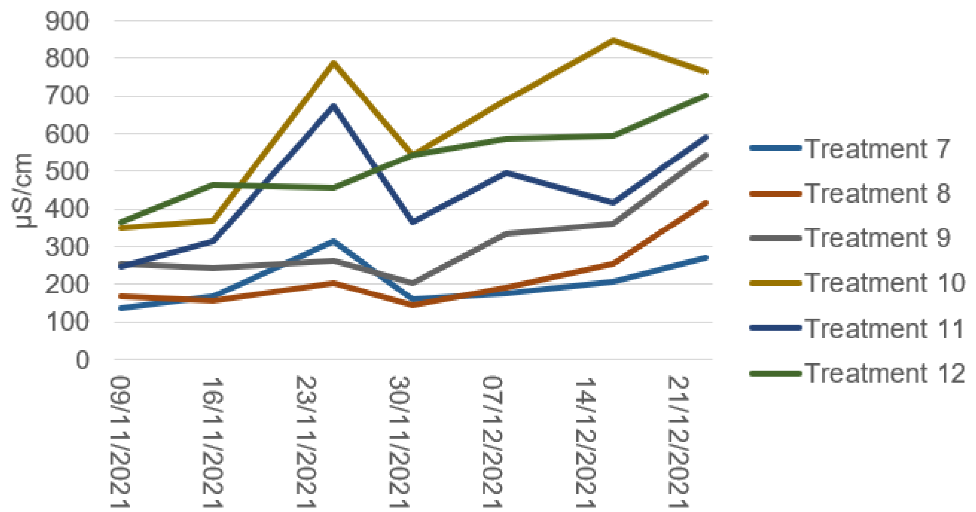

Figure 7. Observations for growing media EC obtained by SME for treatments grown with drip irrigation and capillary matting

Where treatments included drip irrigation with capillary matting the EC levels varied more over the duration of the trial, and in the case of the treatments with CRF the levels were consistently higher.

Discussion

From 2 years of data for the trials of autumn/winter grown pansy we have observed a repeat in the following results:

- The plants grown in the growing media mix with 30% perlite had the highest fresh weight in all combinations of feed and irrigation.
- Where feed was applied only in liquid form, the plants grown using overhead irrigation had the highest fresh weights.
- The highest fresh weights for all growing media mixes were observed where CRF was used.
- The combination of CRF and 30% perlite growing media had the highest fresh weight of all treatments, but flower number was not significantly higher than other growing media mixes with the same fertiliser.
- In each irrigation and feed combination the 30% wood fibre growing media mix had the lowest fresh weights and flower numbers.
- The lowest fresh weight in the trial was observed in the combination of drip irrigation and capillary matting with the liquid feed, with the plants grown in 30% wood fibre growing media mix having the lowest of all of these.

The impact of the growing media components on the pH seen in the first year has not been repeated. Based on the previous results it had been anticipated that there would be the greatest increase in growing media pH in the treatments containing wood fibre, this was not the case. The wood fibre mix had the lowest pH over the duration of the trial and the coir mix had the highest, but the non-peat component is only influencing the trend for pH to a certain degree. Other factors influence pH, and in previous reports the impact of bicarbonate (HCO_3^-) levels in water have been discussed in relation to increase of pH over time. In the 2021/2022 autumn winter trial, water use was very low due to environmental factors, i.e., low light and low temperature, and lower watering will have reduced the potential for HCO_3^- to accumulate in the growing media and cause an increase in pH. Had the water levels been comparable we would have expected to see the same results for pH increase as in 2021/2022 trial.

The temperature during this trial was also lower than in previous years and temperature does have an impact on pH; during monitoring, pH decreases with increase in ambient temperature due to increased ability of water to produce hydrogen ions, lowering pH. As the temperature was lower than the previous year this can be excluded as a reason why the pH may have been observed as lower.

The difference in the components does also need to be taken into consideration. In the introduction to this section the comment was made that over a relatively short period of time the composition of growing media, the source of components and the method of preparing those components will have changed. The perlite used should have remained constant in its properties as it is inert, but the source of peat has changed due to the ban on extraction in Republic of Ireland (now often of Scottish and Baltic origin), and the source and processing method of wood fibre has also changed. This could result in changes in air filled porosity (AFP), cation exchange capacity (CEC) and water retention properties of the growing media, all of these will affect the ability of the media to bind nutrients and make them available to the plants. It is likely that this is the cause of some of the differences in leaf tissue and growing media analysis results over the years.

Use of capillary matting in instances of low water demand by plants has the potential to exacerbate nutrient problems. If liquid feed is used as the nutrient source, the retention of water in the capillary matting reduces the water requirement and consequently the application of feed. Results from previous years show that increasing the feed:water ratio has a positive impact on growth but is not as effective as using overhead irrigation. The holding of water in the capillary matting also has the potential to accumulate unwanted levels of some ions. In Figure 8 below the Cl content of growing media can be seen to be highest in treatment 9, which is more than double the amount of the next highest treatment. High Cl can cause issues with toxicity, with symptoms of yellow halo on the leaf edges, with necrosis effecting the leaf tip initially and then spreading down the leaf, but also incompatibility with other nutrients. Where Cl is high it would be expected that leaf tissue NO_3 is lower, as Cl is considered to limit NO_3 uptake and accumulation in plant tissue.

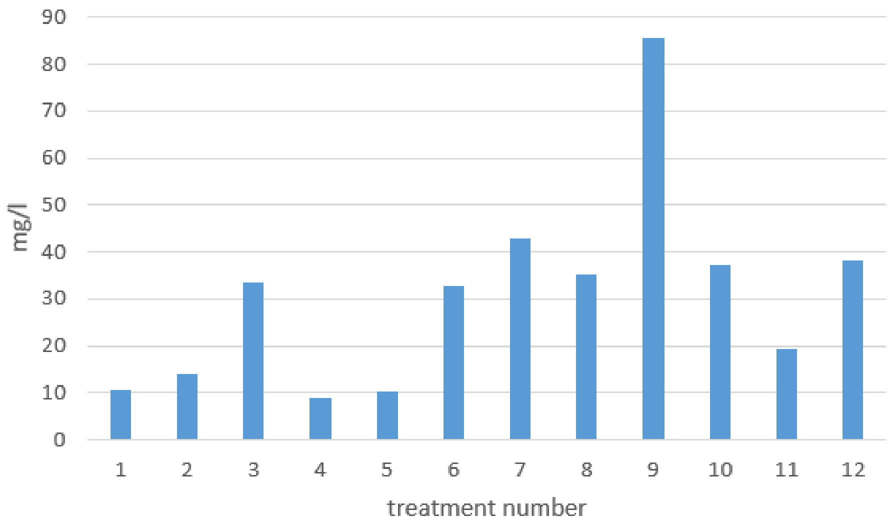

Figure 8. Results for Cl content in growing media in samples dated 06/01/2022.

The data over years shows a trend for higher Cl levels in growing media where capillary matting is used as part of the irrigation system, and in particular the combination of a growing media mixes containing coir and using capillary matting.

Although Cl has been considered a negative factor in N nutrition in plants, and the work in this project appears to demonstrate that, recent studies in tomato and other crop species (Neocleous. D et al, 2021, and Rosales Miguel A. et al, 2020) conclude that Cl has an important role in nitrate use efficiency (NUE) and should be considered as a plant macronutrient. The work does not dismiss the toxic effects of Cl but indicates it is an important nutrient in the assimilation of NO_3 in the plant, and in water use efficiency (WUE) in its own right.

Work from this project reported on in 2019 and 2020 on spring/summer grown petunia looked at plants growing during periods of higher water requirement, the results from these trials showed the plants with the greatest fresh weight were those grown under an ebb and flow irrigation system, followed by overhead irrigation and the lowest was seen in plants grown using drip irrigation and capillary matting. The records taken on irrigation events and volumes of water used, show that the benches watered with ebb and flood irrigation used more water overall but in fewer irrigation events. With overhead watering the volumes of water and consequently of feed were lower, but visually the plants were comparable in both watering regimes, and where the feed concentration was reduced there was no impact on the fresh weight of the overhead irrigated plants.

In previous reports we hypothesised that absorption of nutrient ions through foliar application could be increasing total nutrient uptake, this would still appear to be a valid conclusion to draw. Fertiliser can contain N in up to 3 forms, inorganic in the form of NH_4 and NO_3 and an organic form, urea (CH_4N_2O). Unlike the inorganic forms the CH_4N_2O must be hydrolysed into NH_4 by the enzyme urease (Mekonnen et al, 2021), before it can be utilised by the plant. Plants can take up NH_4 and NO_3 through the roots and foliage, CH_4N_2O can also be absorbed by both plant organs (Bowman and Paul, 1992). Absorption of N by the foliage is the likely reason for the results we have seen for improved efficiency of fertiliser use with overhead irrigation when compared with where feed has been introduced via the roots only.

The conversion process of CH_4N_2O into forms of N the plants can use relies on urease, and urease requires nickel (Ni). A lack of Ni can lead CH_4N_2O to build up to toxic levels in tissues, which shows as necrosis in foliage if it is applied as a foliar fertiliser. Ni is not classed as essential to the plant like copper (Cu), Zn, iron (Fe), boron (B), manganese (Mn) and molybdenum (Mo), but its requirement is essential to the hydrolysis of CH_4N_2O which is arguably the major form of N used in off-the-shelf compound fertilisers.

Urease is found in soil either intracellularly (inside soil microbes) or extracellularly (emitted from cells) and is used to convert urea to NH_4 and carbon dioxide. This process is described as ammonification (mineralisation), and it is vital in making N available to plants and demonstrates the importance of microbial activity within growing media, particularly when using CH_4N_2O.

Growing media mixes now contain a variety of substrates that do not act the way peat does, wood fibre and coir are both re-purposed waste products and the processing method results in them having very few microbes within them. If there is insufficient microbial activity in the growing media urea could leach before it is converted, and in the case of these trials this would result in the loss of most of the N (in 21% N content, 16% was CH_4N_2O). It is difficult to draw conclusion around CH_4N_2O content in the trials as it is not part of a standardised test and the resulting NH_4 and NO_3 produced by urea hydrolysis are the results of biological activity which again is rarely tested for.

To look at microbial activity a brief study was undertaken comparing samples from a newly opened bag of peat with 20% wood fibre growing media mix, with one from the glasshouse that had been used for 9 weeks for growing a brassica crop, using standard laboratory methods on 6 different agar plates. The results showed that overall, there was more microbial activity at 9 weeks than there was in the unused media, an example of one of the plates is shown in Figure 9. Method of testing and results of all the plates are in Tables 1 and 2 of Appendix 4 of the report.

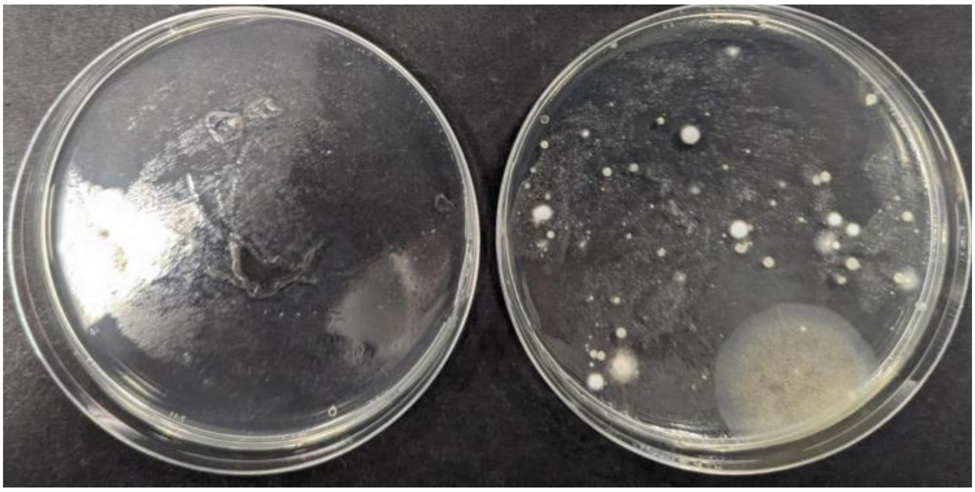

Figure 9. Comparison of microbial activity after 2 days on agar plates from unused (left) and 9 week-old growing media (right), with more bacterial present on used growing media

This shows that there is a real risk of CH_4N_2O leaching from the growing media in the early stages of a crop.

Conclusions

- There is a need to consider different strategies for applying feed according to different levels of water demand, this could either relate to crop type or weather conditions.
- Where water use is high to moderate, overhead irrigation provides the most efficient delivery of liquid feed with both crops examined. The fresh weight is not as great as with ebb and flow irrigation under the same conditions, but the feed concentration can be reduced with no impact on the finished plants.
- Using a liquid feed at every irrigation with NPK ratio of 21-7-21 + 1.6 MgO + TE made up to a stock solution of 1 kg/10 l and diluted 1:200, is a successful delivery method for spring/summer petunia production. The same feed applied to autumn pansy production is successful where water demand is consistently high.
- Where water use is low to very low the feed to water ratio must be increased to ensure adequate supply of feed, but a more successful strategy is to use a CRF to eliminate the need to apply water to supply feed. This will enable growers to apply best practice to watering to avoid problems such as botrytis, root diseases.
- A CRF used in combination with perlite is particularly effective as the perlite has the effect of increasing the AFP of the mix, but also allowing efficient uptake of water by enhanced capillary action (Bragg, 1995).
- Using a CRF with NPK ratio of 12-7-18 + TE, and a release time of 2 to 3 months, incorporated at a rate of 3 g per l of growing media, is a successful delivery method for autumn winter pansy production.

- Mixes with wood fibre as the main non-peat component have a greater feed requirement than those with an inert material or coir.
- Natural properties of coir mean that growing media mixes high in coir can be higher in K, this should be accounted for in the quantity of K in any feed applied used to avoid problem associated with excess K particularly N deficiency.
- Weekly monitoring of growing media pH and EC should be undertaken to allow for modification of feed regimes in response to changes in these levels, it is important to be consistent in the timing of SME tests in relation to feed applications.
- In hard water areas look out for increasing growing media pH over time as this is a problem, particularly with high use of overhead irrigation. This can cause issue with Fe deficiency, due to HCO_3^- induced chlorosis.
- Where capillary matting is used, high growing media EC levels can indicate problems with excess nutrients and indicate potential toxicity, or conditions leading to root damage.
- Testing of irrigation water for nutrient content is important as liquid feeds can be tailored to the water quality for optimal efficiency. It can also identify high levels of nutrients that may lead to toxicities such as Cl should they build up in the crop. Be particularly vigilant when changing water sources such as from stored to mains water.

Knowledge and Technology Transfer

ICL Hortscience online event 2021 – video presentation – Impact of irrigation systems on delivery of liquid feed.

AHDB Knowledge Library pages:

- How to monitor for nutrient management in glasshouse crops
- Interactions between irrigation method and liquid feed
- Interactions between growing media and liquid feed
- Effective application of liquid fertiliser to bedding crops
- When using a CRF may be a better option
- Iron nutrition in bedding crops

Glossary

Air Filled Porosity (AFP) is the growing media's ability to hold "air" which is recorded as a percentage. Oxygen, as a part of the air is essential for plant roots which require an aerobic environment to thrive.

Ban on peat extraction in Republic of Ireland - Commercial peat harvesting was effectively banned by the Irish High Court in 2019, which found large-scale harvesting required planning permission as well as a licence from the EPA, and detailed environmental impact assessments, required under EU law.

Cation Exchange Capacity (CEC) is a property of growing media or soil that describes its ability to supply positively charged nutrient ions such as K^+, Ca^+, Mg^+ (cations) to the soil solution for plant to absorb.

A controlled release fertiliser (CRF) uses water, temperature, and microbial activity to slowly breakdown over and release nutrients over a specific period of time, often a number of months.

Electrical conductivity or EC is the ability of a solution to conduct an electrical current. In solution cations and anions can hold a current which can be measured in microsiemens (us/sq cm) or milli Siemens (ms/sq cm).

Nitrate Use Efficiency (NUE) is a measure of the vegetative or reproductive biomass yield per unit of N available in the soil.

The abbreviation pH denotes the potential of hydrogen or the power of hydrogen. pH is a measure of acidity or alkalinity, depending on how many hydrogen or hydroxyl ions there are. The more hydrogen ions the more acidic, the more hydroxyl ions the more alkaline. The pH scale runs from 1 to 14 with seven being neutral. The scale is logarithmic, meaning pH-4 is 10 times as acidic as pH-5 and 100 times more acidic than pH-6.

Saturated media extraction (SME) is where a soil/substrate sample is diluted down using distilled water (2:1 ratio – distilled water: soil/substrate) and passed through a filter to extract a solution, this can be tested for EC & pH.

Water Use Efficiency (WUE) is defined as the amount of carbon assimilated as biomass produced per unit of water used by the crop.

Urease is an enzyme found in soil either intracellularly (inside soil microbes) or extracellularly (emitted from cells) and converts urea to ammonium and carbon dioxide. This process, which is part of the nitrogen cycle is described as ammonification (mineralisation).

Ammonification (mineralisation) - In soil /substrate urease converts urea (CH4N2O), an organic source of N into ammonia NH4+ and carbonic acid. Urea hydrolysis relies on soil/substrate microbes to aid in this process.

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Appendices

Appendix 1. 2021/2022 autumn winter trial data

Table 1. Plant height

Plant height (cm) 06/01/2022

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	4.80	4.50	4.20	5.10	3.80	4.20	3.80	3.40	3.20	6.70	6.70	7.00
	4.40	3.20	3.40	5.60	4.10	3.80	3.40	3.20	3.60	5.40	6.70	6.70
	5.40	3.90	4.70	4.20	4.20	3.40	3.50	3.60	3.10	7.40	6.40	6.70
	5.70	3.60	5.10	4.00	4.10	4.20	4.10	3.40	3.80	7.80	6.40	7.80
	3.00	3.80	4.00	5.10	4.00	4.40	4.10	4.40	3.40	7.40	5.60	6.40
	4.40	3.40	4.40	3.60	4.10	2.90	4.60	3.40	4.60	6.20	6.50	6.80
Average	4.62	3.73	4.30	4.60	4.05	3.82	3.92	3.57	3.62	6.82	6.38	6.90

Analysis of variance

Variate: height_cm

Source of variatior	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	5	2.1024	0.4205	1.19	
Rep.*Units* stratum					
Treatment_no	11	105.2349	9.5668	27.17	<.001
Residual	55	19.3693	0.3522		
Total	71	126.7065			

Message: the following units have large residuals.

Rep 2 *units* 10	1.235	s.e. 0.519
Rep 5 *units* 7	-1.557	s.e. 0.519

Tables of means

Variate: height_cm

Grand mean 4.693

Treatment_	1	2	3	4	5	6	7
	4.617	3.733	4.3	4.6	4.05	3.817	3.917

Treatment_	8	9	10	11	12
	3.567	3.617	6.817	6.383	6.9

Least significant differences of means (5% level)

Table	Treatment_no
rep.	6
d.f.	55
l.s.d.	0.6866

Table 2. Number of flowers

Number of flowers 06/01/2022

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	2.00	0.00	2.00	2.00	0.00	1.00	1.00	0.00	0.00	6.00	8.00	6.00
	0.00	0.00	0.00	1.00	2.00	3.00	1.00	0.00	0.00	4.00	7.00	4.00
	1.00	1.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	4.00	6.00	7.00
	2.00	2.00	3.00	5.00	0.00	1.00	0.00	0.00	0.00	9.00	2.00	5.00
	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	7.00	4.00	7.00
	2.00	1.00	2.00	0.00	0.00	1.00	0.00	1.00	0.00	8.00	3.00	5.00
Average	1.17	0.83	1.50	1.50	0.33	1.17	0.33	0.17	0.17	6.33	5.00	5.67

Analysis of variance

Variate: number_of_flowers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	5	4.903	0.981	0.56	
Rep.*Units* stratum					
Treatment_no	11	340.486	30.953	17.81	<.001
Residual	55	95.597	1.738		
Total	71	440.986			

Message: the following units have large residuals.

Rep 4 *units* 5	-3.4	s.e. 1.15
Rep 4 *units* 10	3.1	s.e. 1.15

Tables of means

Variate: number_of_flowers

Grand mean 2.01

Treatment_	1	2	3	4	5	6	7
	1.17	0.83	1.5	1.5	0.33	1.17	0.33

Treatment_	8	9	10	11	12
	0.17	0.17	6.33	5	5.67

Least significant differences of means (5% level)

Table	Treatment_no
rep.	6
d.f.	55
l.s.d.	1.525

Table 3. Above ground fresh weight

Above ground growth fresh weight (g)

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	9.61	6.07	8.63	9.06	5.90	8.65	6.48	4.26	4.67	14.43	14.65	14.79
	8.61	5.45	6.57	8.17	7.00	7.48	4.43	4.39	3.48	14.44	14.92	14.46
	6.49	5.82	9.00	7.36	5.50	8.06	4.51	3.86	4.09	17.39	15.20	16.08
	12.45	7.87	10.86	9.06	6.00	6.84	4.17	4.20	5.00	15.59	10.93	16.30
	6.94	6.84	6.74	6.95	6.14	7.68	5.17	3.48	4.28	21.12	12.53	13.79
	6.72	5.86	8.13	7.80	6.75	8.00	4.18	3.67	4.03	13.89	11.41	14.68
Average	8.47	6.32	8.32	8.07	6.22	7.79	4.82	3.98	4.26	16.14	13.27	15.02

Analysis of variance

Variate: fresh_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	5	11.106	2.221	1.16	
Rep.*Units* stratum					
Treatment_no	11	1117.906	101.628	53.07	<.001
Residual	55	105.323	1.915		
Total	71	1234.336			

Message: the following units have large residuals.

Rep 4 *units* 5	-2.89	s.e. 1.21
Rep 4 *units* 7	3.43	s.e. 1.21
Rep 5 *units* 4	5.06	s.e. 1.21

Tables of means

Variate: fresh_weight

Grand mean 8.56

Treatment_	1	2	3	4	5	6	7
	8.47	6.32	8.32	8.07	6.21	7.78	4.82

Treatment_	8	9	10	11	12
	3.98	4.26	16.14	13.27	15.02

Least significant differences of means (5% level)

Table	Treatment_no
rep.	6
d.f.	55
l.s.d.	1.601

Appendix 2. 2021/2022 autumn winter leaf tissue and growing media laboratory analysis

Table 1. Pansy leaf tissue SAP analysis sampled 06/01/2022

Treatment number	Feed code	Growing media type	Irrigation code	RESULTS (are expressed as mg/l) PH	NH4	NO3	Al	B	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
1	L	SA	IA	6.42	43.49	6.65	0.13	2.88	525.1	0.7	1.93	3597	1013.8	25.88	0.25	434.3	456.8	277.8	7.05
2	L	SB	IA	6.52	8.26	26.84	0.14	2.75	438.5	0.71	1.86	4736	714.44	31.34	0.24	222.5	470.2	286.2	7.63
3	L	SC	IA	6.50	47.26	67.72	0.15	2.61	361.9	0.67	1.71	5299	548.23	16.22	0.19	298.1	662.1	227.7	6.57
4	L	SA	IA	6.41	45.48	7.49	0.14	2.98	547.7	0.64	1.92	3609	1020.4	26.62	0.21	386.2	442.7	267.3	6.46
5	L	SB	IA	6.48	39.34	0.86	0.23	2.59	474.9	0.62	1.96	4099	749.03	36.93	0.2	273.6	364.7	266.2	7.04
6	L	SC	IA	6.55	42.87	7.15	0.18	2.49	388.2	0.61	1.82	5347	558.3	18.52	0.2	271	620.9	238.3	6.44
7	L	SA	IC	6.50	28.29	4.12	0.32	2.9	613.7	0.45	1.55	3670	1056.6	42.9	0.32	759.5	153	209.3	7.57
8	L	SB	IC	6.51	29.50	3.15	0.25	2.89	461.2	0.43	1.43	4265	727.84	54.33	0.31	512.7	217.1	207.3	6.75
9	L	SC	IC	6.42	31.95	1.23	0.29	2.16	356.2	0.5	1.69	5073	551	28.47	0.3	639.4	372.1	160	5.78
10	CRF	SA	IC	6.38	55.43	339.73	0.26	2.83	603.9	0.58	1.83	5338	1109.5	32.11	0.15	331.4	477.1	315.7	6.08
11	CRF	SB	IC	6.39	47.20	141.39	0.13	2.68	411.1	0.49	1.68	4785	851.76	34.25	0.28	208.3	339	273.4	6.1
12	CRF	SC	IC	6.39	45.68	224.06	0.17	2.65	323.6	0.44	1.36	5343	586.33	14.33	0.12	356.6	439.2	232.5	5.44

Table 2. Growing media analysis, sampled 06/01/2022

Treatment number	Feed code	Growing media type	Irrigation code	pH	EC @20c (µS/cm)	density (kg/m3)	dry matter (%)	dry density (kg/m3)	RESULTS (are expressed as mg/l) Cl	P	K	Mg	Ca	Na	NH4	NO3	total sol N	S (SO4)	B	Cu	Mn	Zn	Fe
1	L	SA	IA	5.3	36	395	31.8	125.6	10.6	<1	3	3.4	4.9	20.6	1.8	1	2.8	66.1	0.05	<0.01	<0.01	<0.02	0.58
2	L	SB	IA	5	39	406	31.4	127.5	13.9	<1	3.3	3.8	5	20.3	1.2	0.8	2	66.5	0.06	<0.01	<0.01	<0.02	0.7
3	L	SC	IA	5.9	70	437	24.3	106.2	33.6	<1	54	0.8	2.6	31	0.9	1.1	2	87	0.13	<0.01	<0.01	0.03	1.37
4	L	SA	IA	5.3	29	406	28	113.7	8.9	<1	2	1.8	3.5	16.9	0.9	0.9	1.8	48	<0.05	<0.01	<0.01	<0.02	0.52
5	L	SB	IA	4.9	34	408	32	130.6	10.1	<1	2.6	2.5	3.8	17.6	0.7	0.8	1.5	53.9	<0.05	<0.01	<0.01	<0.02	0.57
6	L	SC	IA	6	61	466	22.9	106.7	32.9	<1	41.6	0.7	2.9	26	0.7	1	1.7	72.6	0.13	<0.01	<0.01	<0.02	1.07
7	L	SA	IC	5.2	58	394	29.8	117.4	42.9	<1	3.8	6.8	7.5	30.1	0.8	0.8	1.6	72.4	<0.05	<0.01	<0.01	<0.02	0.37
8	L	SB	IC	4.9	49	421	33.8	142.3	35.1	<1	2.9	5.4	6	25	0.6	0.8	1.5	56.7	<0.05	<0.01	0.01	<0.02	0.35
9	L	SC	IC	5.7	112	449	24.6	110.5	85.6	1	80	1.5	3.8	45.4	1.1	0.9	1.9	93.7	0.1	<0.01	<0.01	<0.02	0.86
10	CRF	SA	IC	4.8	265	412	29.5	121.5	37	5.6	59	42.5	54.6	51.1	7.5	32.8	40.3	366.5	0.35	0.04	0.13	0.1	1.56
11	CRF	SB	IC	4.5	255	383	35.2	134.8	19.2	4	52.8	37.8	40	40.7	14.4	20.6	35	360.2	0.34	0.03	0.18	0.07	2.22
12	CRF	SC	IC	5.1	276	410	29.5	120.9	38.2	5.2	153.1	20.6	26.7	64.2	2.4	32.5	34.9	317.5	0.28	0.04	0.04	0.05	2.32

Table 3. Growing media analysis for EC

Growing media EC (µS/cm) readings taken by SME

Date	Temp (°C)	Treatment number 1	2	3	4	5	6	7	8	9	10	11	12
09/11/2021	22.5	131	140	234	159	184	222	135	169	253	350	248	366
16/11/2021	16.2	108.7	106.2	208	93.6	80.4	136.7	169.2	156.4	242	368	315	464
25/11/2021	13.2	88.8	109.1	203	83.9	139.9	219	312	202	261	789	675	457
01/12/2021	11.6	106	175	277	111	259	227	158	144	203	543	363	541
08/12/2021	10.5	110.8	120.9	241	111.8	152.1	214	174.8	190.6	335	688	497	586
16/12/2021	14.5	165.1	166.3	216	95.2	128.6	199.1	207	253	361	845	415	596
23/12/2021	12	150.9	362	267	152.9	148.9	244	269	415	544	762	591	702

Table 4. Growing media analysis for pH

Growing media pH readings taken by SME

Date	Temp (°C)	Treatment number 1	2	3	4	5	6	7	8	9	10	11	12
09/11/2021	22.5	4.93	5.02	4.49	4.36	3.95	4.07	4.60	4.12	4.75	4.69	4.90	4.77
16/11/2021	16.2	4.20	4.18	4.51	4.25	4.13	4.41	4.93	4.55	4.82	4.42	4.15	4.28
25/11/2021	13.2	6.69	6.39	6.76	6.38	6.03	6.69	5.98	5.94	6.49	5.73	5.56	6.34
01/12/2021	11.6	6.52	6.19	6.48	6.31	5.78	6.82	6.27	6.05	6.58	5.89	5.63	6.08
08/12/2021	10.5	6.99	6.12	7.01	6.95	6.51	7.57	6.3	6.12	6.55	5.94	5.86	6.18
16/12/2021	14.5	6.01	5.74	6.69	6.15	5.87	6.85	6.16	5.91	6.26	5.89	5.45	5.71
23/12/2021	12	5.77	5.41	5.93	5.48	5.18	6.02	6.13	5.92	6.84	5.74	5.53	5.87

Appendix 3. 2020/2021 autumn winter trial images

Images dated 06/01/2022

	
Treatment 1	Treatment 2
	
Treatment 3	Treatment 4
	
Treatment 5	Treatment 6
	
Treatment 7	Treatment 8

	
Treatment 9	Treatment 10
	
Treatment 11	Treatment 12

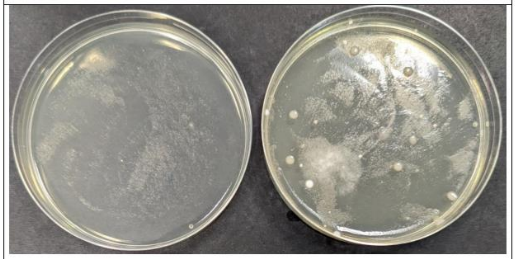
Appendix 4. Results of microbial activity assay on growing media

Table 1. Media description and ingredients

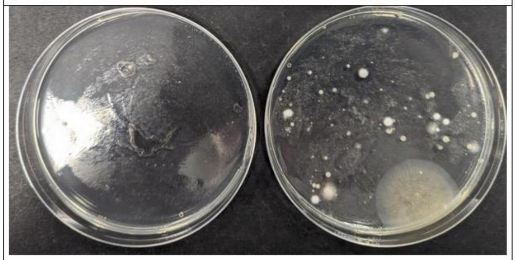
Agar code	**A**	**F**	**G**	**H**	**I**	**N**	**Z**
description	Potato dextrose agar	Psuedomonas F agar + additives	Sucrose Nutrient Agar with additives (SNA + A)	mCS20ABN	FS agar	Malt agar with streptomycin	Potato dextrose agar
Ingredients	Distilled water	Distilled water	Distilled water	Distilled Water	Distilled Water	Distilled water	Distilled water
	PDA powder	Pseudomonas F agar	Nutrient agar	Soya Peptone	K2HPO4	Oxoid technical agar	PDA powder
		Glycerol	Sucrose	Tryptone	KH2PO4	Holland & Barrett malt extract	
		Cephalexin stock solution (8g/L)	Cephalexin stock solution (8g/L)	KH_2PO_4	KNO3	Streptomycin solution	
		Boric acid stock solution (37.5g/L)	Boric acid stock solution (37.5g/L)	$(NH_4)_2HPO_4$	MgSO47H2O		
				$MgSO_47H_2O$	Yeast Extract		
				L-Glutamine	Soluble starch		
				L-Histadine	Agar Agar		
				Soluble starch	Methyl Green 1% aqueous solution		
				Agar Agar	Nystatin Sol^{n} (100mg in 10ml 50% ethanol)		
				Neomycin Sol^{n} (200mg in 10ml sterile distilled water)	D-Methionine Sol^{n} (10mg in 10ml 50% ethanol)		
				Bacitracin Sol^{n} (500mg in 10ml 50% ethanol)	Pyriodoxine HCl Sol^{n} (10mg in 10ml 50% ethanol)		
				Nystatin Sol^{n} (100mg in 10ml 50% ethanol)	Cephalexin Sol^{n} (200mg in 10ml 50% ethanol)		
					Trimethroprim Sol^{n} (100mg in 10ml 70% ethanol)		

Table 2. Images of plates 48 hours after inoculation at 28 ºC, all images showing plates of unused growing media (left) compared with 9 week-old growing media (right).

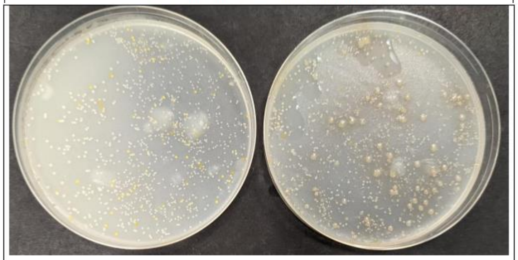
F agar – fewer bacteria present on 326



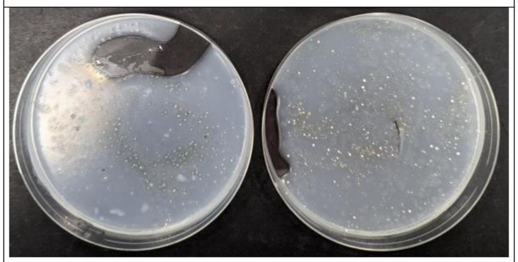
G agar – fewer bacteria present on 326



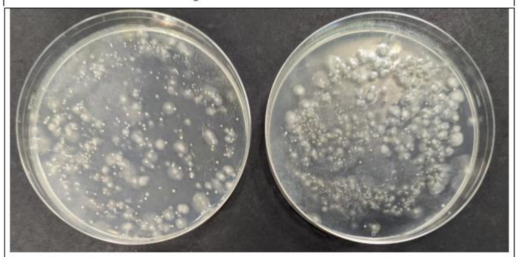
H agar – slightly fewer bacteria present on 326



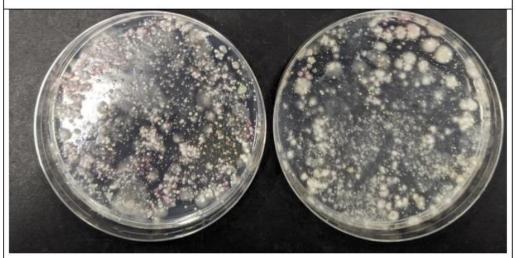
I agar - slightly fewer bacteria present on 326



N agar – no noticeable difference



Z agar - no noticeable difference



Introduction – Section 2. Improved Primula nutrition to reduce leaf edge scorch

Primula is a crop that is susceptible to marginal leaf necrosis which is frequently referred to as "leaf edge scorch". The cause of this is suspected to be related to nutrition but no evidence-based knowledge currently exists in the UK industry.

During the project scoping study little directly relevant investigation on this crop was found, although analogous work was identified on lettuce (Collier, G.F & Tibbitts, T.W. 1984) (and other leafy vegetables) and in poinsettia (Bierman et al 1990), both of which identify Ca as a factor in leaf edge burn/scorch. Work on B (Hu, H. & Brown, P.H. 1997, Brown, P.H. & Shelp, B.J. 1997) also demonstrates young leaf necrosis as a symptom of deficiency, and necrosis of the mature leaf margin as a symptom of toxicity.

Absorption and movement of both Ca and B in the plant are affected by transpiration rates, with low levels being transported to areas of low transpiration. Uptake is also affected by the pH of the substrate, with high pH associated with B deficiency.

Experimental work was designed and carried out to look at B and Ca in conjunction with glasshouse environmental conditions, to see if either of these nutrients were the cause of the symptoms, and if control of humidity could alleviate symptoms.

A total of 4 trials were carried out in the period from 2019 to 2022. The trial work carried out in 2019/2020 winter is described in the document POBOF 003 annual report 2019, and work completed in summer of 2020 is described in the document POBOF 003 annual report 2020. In this work Ca was identified as a more likely cause, and work on how to improve Ca nutrition continued in the later trials.

Materials and methods

Between September 2020 and January 2021 an investigation was undertaken to see if the results obtained in summer 2020 were repeated under different seasonal conditions. The trial was grown in a glasshouse at NIAB's Cambridge trial site. The glasshouse was set to maintain a minimum temperature of 10 ^{o}C, no supplementary lighting was provided, and no shade screens were utilised. The trial was carried out on a tabletop bench fitted with Stal & Plast liners.

The test plant was Primula 'Cresendo® Orange', these were obtained from Ball Colegrave as plug plants and were received on 18/09/2020. Four days after receipt the plants were transplanted into Aeroplas 9 cm Low 5 deg. Pots using a standard peat based growing media mix, the specification of which can be found in Table 6.

Table 6. Growing media specification.

Brand	ICL M2
pH range	5.3-6.0
Particle size	0-10 mm
Conductivity	228-414 µs
Nutrient added	192N 98P 319K

Ca was supplied from high levels in the irrigation water and from the liming material used in the growing media. Additional Ca was added to eight treatments in the form of foliar applications of calcium nitrate ($Ca(NO_3)_2$). A liquid formulation of the compound containing 22.5% Ca, 15% N with no other micro or macronutrients was used and applied as a foliar feed at weekly intervals from 28/10/2020 at two rates, 1:500 (0.2%) & 1:1000 (0.1%).

To maintain all other nutrients to an acceptable level all plants were fed once per week with Omex feed O-Mix 21-7-21 + 1.6 MgO + TE (diluted into stock then 1:200) 5 ml diluted feed once a week.

Additional applications of the product 'Maxicrop plus Iron' (seaweed extract base with 2% sequestered iron) to combat Fe deficiency were made following the development of deficiency symptoms early in the trial. These were applied weekly to all treatments, for 4 weeks from 30/10/2020 at 5 ml in 1 l water.

Irrigation to the trial was applied manually overhead using a lance. The water supply used was mains supply for the area (hard water). The two water regimes used in the summer trial 2020 were repeated as detailed in Table 7.

Table 7. Results of chemical analysis for the irrigation water at the Cambridge site.

	*		mg/l																µg/l
Sample	pH	EC µS/cm	nitrate N	SO4	B	CU	Mn	Zn	Fe	Cl	P	K	Mg	Ca	Na	Carbonate	hardness as CaCO3	Alkalinity as HCO3	dissolved Mo
Glasshouse irrigation water	7.7	611	9.8	30.8	0.03	<0.01	<0.01	<0.01	<0.01	39	0.8	2.7	3.74	116.6	16.7	<10	306.5	277	0.31

*pH and conductivity measurements made at 20 ºC.

All plants were allowed to drain freely following irrigation events, with no water recycling.

Table 8. Treatment list for 2020/2021 autumn/winter primula trial.

Treatment code	1	2	3	4	5	6	7	8	9	10	11	12
Water rate	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low
Humidity level	low	high	low	high	low	high	low	high	low	high	low	high
Calcium foliar feed	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Foliar feed rate	-	-	-	-	1:500	1:500	1:500	1:500	1:1000	1:1000	1:1000	1:1000

Figure 10. Overview of trial set up; image dated 22/01/2021.

49 plants for each treatment were grown and arranged in single blocks, without any randomisation of the treatments. Plants were arranged in seven-by-seven row block, in a staggered arrangement, the edge plants of each block were excluded from the assessments.

The two humidity levels were created using different plant spacing regimes, these are detailed in Figure 11 below.

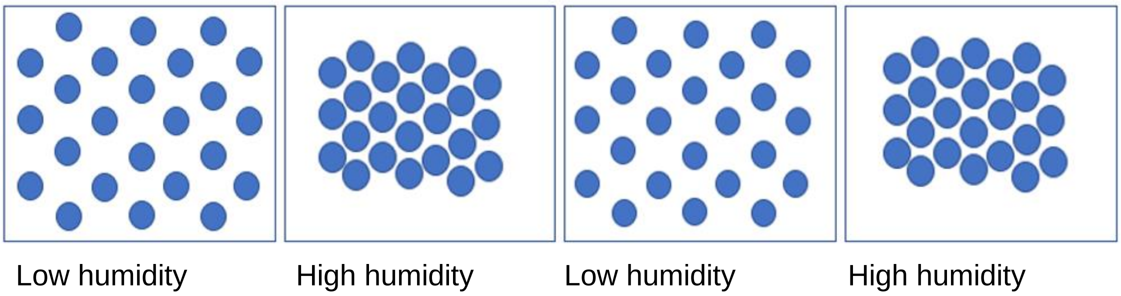


Figure 11. Illustration of plant spacing to create humidity treatments in trial design (not to scale)

The temperature and humidity were monitored at crop leaf height using Blue Maestro Tempo Disc™ 3 in 1 Bluetooth environmental monitors.

Observations were made throughout the trial on the incidence of deficiency symptoms, and where 'Leaf-edge scorch' was observed the number of plants showing symptoms and the percentage of each plants affected were recorded and photographed.

Assessment of plant width in millimetres (mm) was made on two occasions during the trial, and at the final assessment there was a count of the number of flowers, and measurement of the fresh weight of above ground growth in g.

A sample of plant tissue and growing media from each treatment was also sent for laboratory analysis at the end of the trial. The material sent was a bulk sample taken from at least 10 randomly selected plants.

Between September 2021 and February 2022 this trial was repeated according to the same method to see if the results repeated. The trial set up, irrigation, and feed regime was the same but with additional treatments that provided an increased concentration of the foliar applications of $Ca(NO_3)_2$ at a dilution of 1:250. This resulted in a total of 16 treatments with all combinations of water rate, humidity level, and foliar feed rate, as shown in Table 9 below.

Table 9. Treatment list for 2021/2022 autumn/winter Primula trial.

Treatment code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Water rate	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low
Humidity level	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
Ca foliar feed	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Foliar feed rate	-	-	-	-	1:250	1:250	1:250	1:250	1:500	1:500	1:500	1:500	1:1000	1:1000	1:1000	1:1000

In this trial the test plant was Primula 'Cresendo® Orange', these were obtained from Volmary Ltd as plug plants and were received on 06/10/2021. On 13/10/2021 the plants were transplanted into Aeroplas 9 cm Low 5 deg. Pots using a peat reduced growing media mix which contained 20% wood fibre. The change to peat reduced growing media is in line with changes experienced by growers.

The trial design was unchanged apart from the inclusion of additional treatments, and the observations remained the same, but plant width was only observed at the end of the trial.

Figure 12. Overview of trial set up; image dated 09/12/2021.

For both trials no chemical pest or disease treatment was undertaken, control of pests was via a program of biological control agents.

No plant growth regulator was applied during the trial.

Results

In the trial carried over winter 2020/2021 no symptoms of leaf edge scorch were observed in any of the treatments. All combinations of humidity, water, and feed treatment resulted in healthy plants. However, it was noticeable that under the higher humidity the plants produced had elongated, stretched leaves that were visually less appealing. This can be seen in Figure 13 below. Other trial images can be found in Appendix 7 and Appendix 11 of this report.

	
Treatment 1	Treatment 2

	
Treatment 3	Treatment 4
	
Treatment 5	Treatment 6
	
Treatment 7	Treatment 8
	
Treatment 9	Treatment 10

	
Treatment 11	Treatment 12

Figure 13. Images of 3 typical plants from each treatment at final assessment, dated 25/01/2021.

Although not the main aspect of the investigation it was noted from the results for the leaf tissue analysis that rates of N in the leaf tissue were lower in the higher humidity treatments, which correlates to the elongated, stretched leaves which in addition were observed to be paler green.

The results for plant fresh weight split the treatments according to water rate, with the lowest fresh weight results for the treatments with low water rates, and the higher water rate giving the heavier plants. Where water rate was high the level of humidity did not impact on the fresh weight, but where water rate was low, those plants grown under the low humidity were the lowest results for fresh weight.

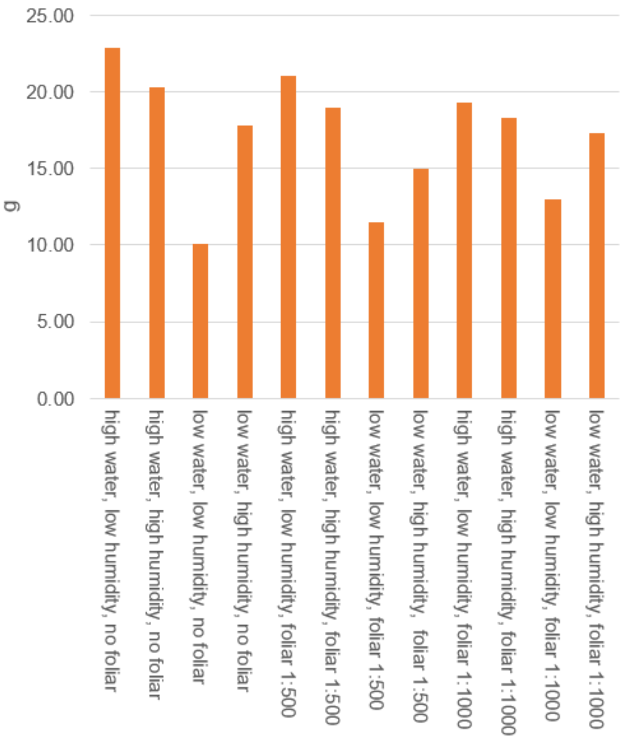


Figure 14. Graph with results for fresh weight of above ground growth (g) at final assessment (in treatment order 1 to 12 from left to right), observations dated 25/01/2021.

The application of $Ca(NO_3)_2$ did not have any impact on the fresh weight of the plant. The full results for other observations on the trial can be found in tables 1,2,3, and 4 of Appendix 5 of this report.

As the application of routine liquid fertiliser was the same for all treatments irrespective of the water rate, we can conclude that the difference is not due to the amount of nutrient applied. This is confirmed by the results of the growing media analysis, as shown in Table 10 below, the treatments with low water rate have higher NO_3 content at the end of the trial than those with the higher water rate. The full results for growing media analysis can be found in Table 1 of Appendix 6 of this report.

Table 10. Results of leaf tissue and growing media analysis for Ca, NH_4, and NO_3 content and Ph, samples taken on 25/01/2021

Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Water rate	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low
Humidity level	low	high	low	high	low	high	low	high	low	high	low	high
$Ca(NO_3)_2$ foliar feed	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Foliar feed rate	-	-	-	-	1:500	1:500	1:500	1:500	1:1000	1:1000	1:1000	1:1000
Leaf tissue analysis (mg/l)												
Ca	348	523	282	424	326	367	234	379	302	274	196	423
Growing media analysis (mg/l)												
Ph	6.1	5.9	5.3	5.6	5.8	6	5.3	5.5	5.7	5.9	5.4	5.5
Ca	18	13.7	50.4	26.7	25.7	12	85.3	41.3	29.4	12.6	52.6	26.8
NH4	1.1	1.4	1.1	0	1.2	1.5	1.4	2.8	1.1	1.1	0	1.2
NO3	1.3	9.1	37.5	14.2	2.4	8.7	62.5	42.4	5.4	10	21.7	16.1

The full results for leaf tissue analysis can be found in Table 2 of Appendix 6 of this report.

When comparing the results for Ca content of the leaf tissue the analysis shows that the combination of low water and low humidity all produce tissue with low levels of Ca. Whereas the high humidity and high water rates are inconsistent in the Ca content of the leaf, with both high and low levels being observed.

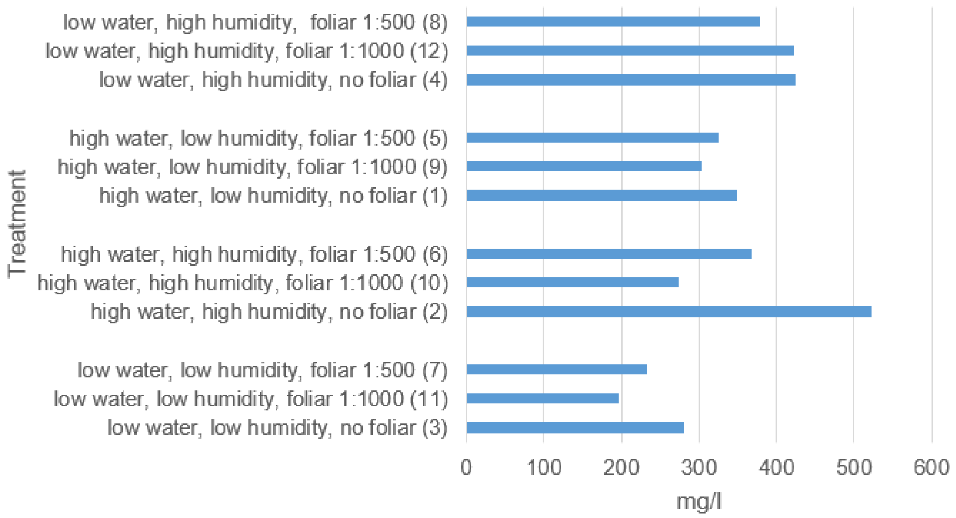


Figure 15. Results for Ca content of leaf tissue from samples dated 25/01/2021, grouped according to treatment variables of water rate and humidity.

The low humidity and low water combination of humidity and water all have low Ca content in the leaf, whereas the low humidity and high water are consistently in the mid-range for Ca. This is also true for the high humidity and low water rate, irrespective of the use of foliar feed. In relation to the use of $Ca(NO_3)_2$ as a foliar feed treatment in this trial, the results indicate that there was no positive effect of using it at these concentrations. The results do appear to indicate that there was a negative impact from the lowest rate of $Ca(NO_3)_2$ foliar feed on the Ca levels in the leaf tissue, as in all cases these were lower than in the comparable low/humidity treatments where no foliar feed was applied.

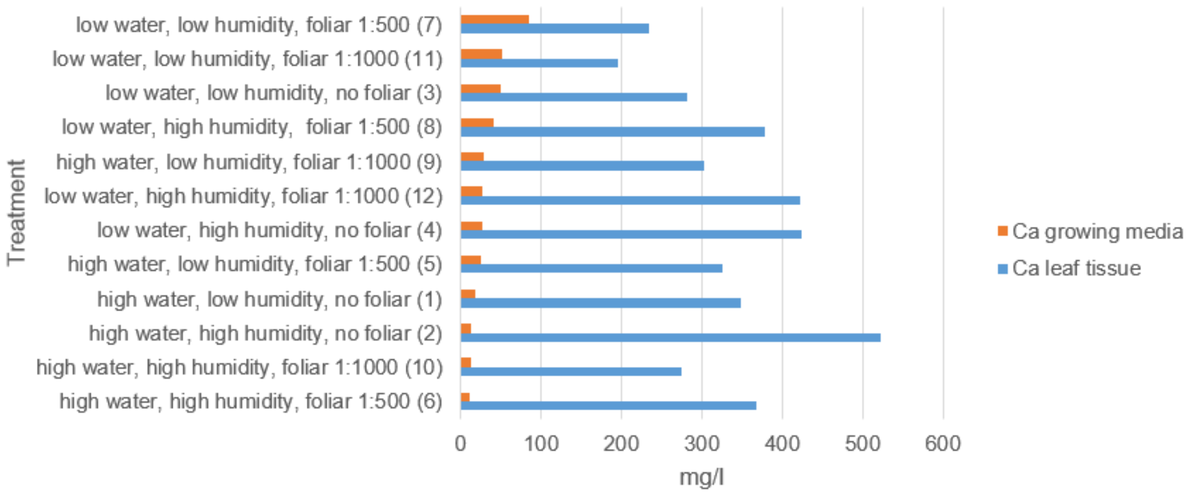


Figure 16. Results for Ca content of leaf tissue and growing media from samples dated 25/01/2021, ranked according to growing media levels.

When looking at the content of Ca in the growing media a clearer pattern is visible, the low water, low humidity treatments have the highest level of Ca remaining in the media and the high water, high humidity treatments have the lowest level of Ca remaining in the media. Although the same pattern is not identical in the leaf tissue analysis this would suggest that the plants are taking up more Ca in the high water, high humidity treatments, particularly as the high water treatments should have more Ca in the growing media from the hard water as it is applied in greater amounts.

There were no symptoms of leaf edge scorch observed in the winter 2021/2022 trial. The results for plant above ground fresh weight (g) as shown in Figure 17 gave results that mirror those seen in the previous trial. The low water, low humidity combination resulted in plants with the lowest fresh weight, and where no foliar $Ca(NO_3)_2$ was applied the highest fresh weight was in the plants with the high water, low humidity treatments. Overall, the application rate of the foliar $Ca(NO_3)_2$ has not impacted greatly on the final fresh weight of the plant, but in the high water treatments those plants subjected to high humidity conditions with foliar $Ca(NO_3)_2$ do appear to have higher fresh weight than the corresponding low humidity treatments.

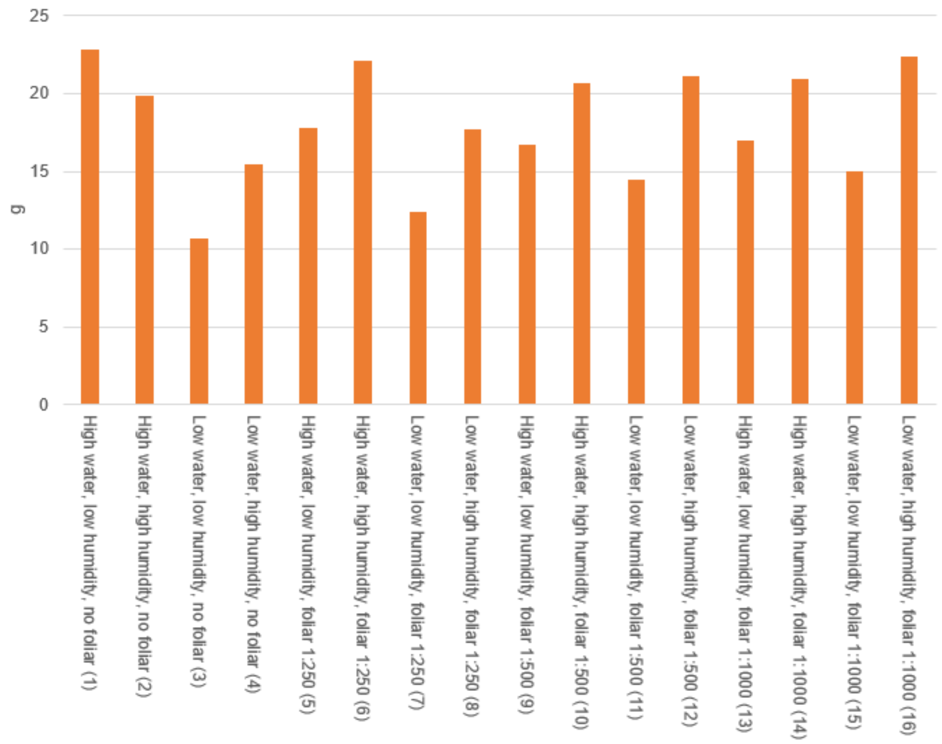


Figure 17. The results for fresh weight of above ground growth (g) at final assessment, observations dated 06/01/2022.

The details of all trial observations can be found in Tables 1, 2, and 3 of Appendix 9 of the report.

When comparing results of the fresh weight of above ground growth with the N content of the leaf from the SAP analysis, in the high humidity conditions the total soluble N is at the highest levels, and it is at its highest where the foliar application of $Ca(NO_3)_2$ has been applied at the 1:250 dilution rate. As shown in Table 11, in all cases most of the N present is in the form of NO_3.

Table 11. Results of plant observations and leaf tissue analysis from samples taken on 06/01/2022.

Treatment	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Water rate	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low
Humidity level	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
Ca(NO3)2 foliar feed	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Foliar feed rate	-	-	-	-	1:250	1:250	1:250	1:250	1:500	1:500	1:500	1:500	1:1000	1:1000	1:1000	1:1000
Plant observations																
Average width (cm)	21.64	20.06	14.92	17.32	17.74	20.5	15.68	19.14	18.24	19.82	16.34	19.84	17.32	20.2	18.5	22.24
Average no. flowers	1.24	0.64	0.44	0.64	1.24	1.042	0.52	0.44	1.2	1.08	0.44	0.76	0.72	0.76	0.64	0.76
Average weight (g)	22.82	19.82	10.69	15.47	17.83	22.15	12.4	17.68	16.73	20.65	14.47	21.16	16.99	20.97	14.96	22.42
Tissue analysis(mg/l)																
Ca	423	370	595	444	423	361	704	545	432	349	626	422	394	453	534	301
NH4	28.26	32.1	36.08	46.25	45.96	37.36	42.02	48.65	47.53	38.78	59.09	49.71	67.03	68.36	75.03	62.54
NO3	121.2	251.9	51.82	396.2	179.9	245.2	128.4	504.7	100.4	169.5	114.2	419.1	80.34	247.1	225	360.42
Total sol. N	149.4	284	87.9	442.4	225.8	282.6	170.4	553.4	147.9	208.3	173.3	468.8	147.4	315.5	300	422.96

The full results from the leaf tissue analysis are contained in Appendix 10 of the report.

The analysis results for Ca content of the leaf tissue show that all treatments have acceptable levels present. The highest levels are found in the low water, low humidity treatments, and the highest level overall is in this combination with the $Ca(NO_3)_2$ foliar feed at the 1:250 dilution rate. The lowest levels of Ca are seen in the treatment with low water and high humidity, followed by high water and high humidity.

When considering the impact of the foliar application of $Ca(NO_3)_2$, where there is high water rate and low humidity, additional foliar feeding has little impact on the level of Ca in the leaf tissue. Where the water rate is lower, the $Ca(NO_3)_2$ foliar application does appear to have an impact but only at the highest concentration, the lower concentrations of 1:500 and 1:1000 have no impact on the Ca level in the leaf tissue.

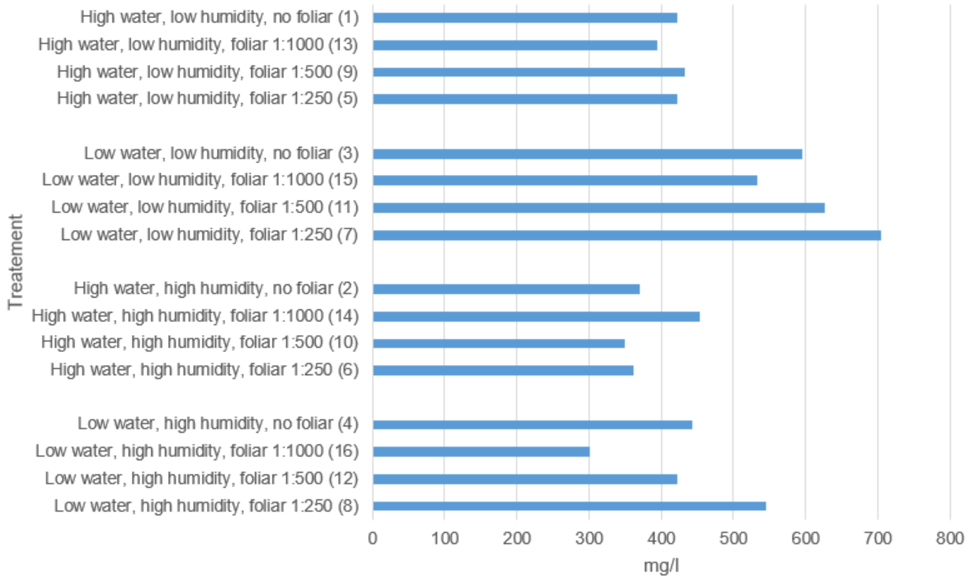


Figure 18. Results for Ca in leaf tissue from SAP analysis (mg/l), samples taken 06/01/2022.

The response to the lower rates of foliar application of $Ca(NO_3)_2$ has not been consistent in one instance, under the high water, high humidity conditions the 1:1000 dilution rate has the greatest amount of Ca in the leaf tissue. In the other rates in this treatment combination of water and humidity, the pattern of response to application of $Ca(NO_3)_2$ has been the same as the other combinations.

In both the 2020 and 2021 trials symptoms of Fe deficiency were observed. Whilst not the main part of this study the application of foliar sequestered Fe, as described in the method, was successful in removing the symptoms of this deficiency.

Discussion

As there have been no symptoms of leaf edge scorch observed over the 2 years of trials in 2020 and 2021, it would suggest that all the levels of Ca in the trial have been sufficient to fulfil the plant requirement in the cell walls of the leaf margins and growing points.

The results of the leaf tissue analysis for Ca over the 2 years of winter trials described in the results are in some respects contradictory, when considering the levels relative to the humidity level and water rate combinations. As shown in the graph in Figure 18, the combination of low water and low humidity had the lowest levels of Ca in the 2020 trial and conversely the highest levels in the 2021 trial. Although the 2 trials were grown at the same period of the year, the values for temperature and humidity in the glasshouses will not have been exactly the same. The average temperature and humidity in all treatments were lower in the 2021 trial than in 2020 trial, see Appendix 8 and Appendix 12 for data, and this is a potential cause of the differences. It can be hypothesised that there is a greater benefit in reducing humidity when temperatures are lower to compensate for the lower transpiration rate and consequently lower movement of Ca, but further work would be needed to confirm this.

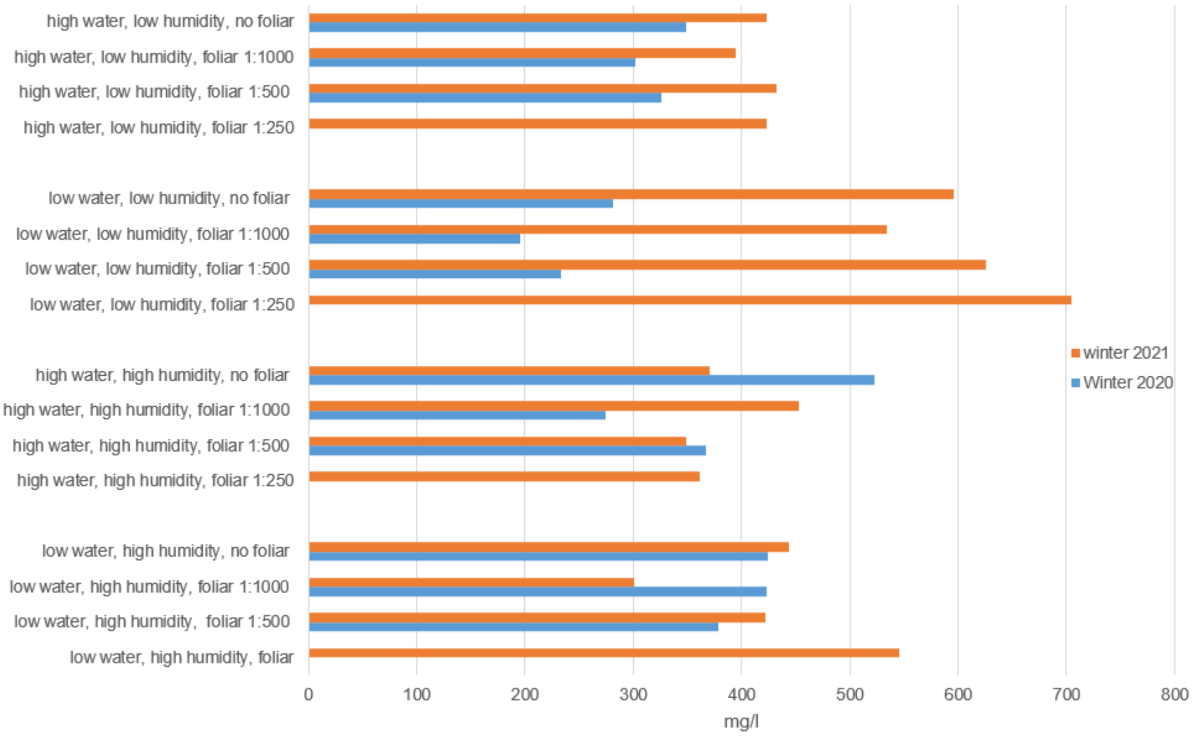


Figure 19. Comparison of Ca content of leaf tissue over 2 years of trial, from samples dated 25/01/2021 and 06/01/2022.

What is more consistent is the response to the low rate application of $Ca(NO_3)_2$. At worst these appear to have a negative impact on the on the Ca level in the leaf, and generally they have no impact at all. As only one year of data exists for the increase dilution rate of 1:250, it is not possible to make a recommendation for its use in the situation but there does appear to be a beneficial impact at this concentration.

During the 2020 trial year samples of growing media and leaf tissue were taken from a nursery growing primula on the south coast of England, these samples were from a grower who had seen issues with Leaf Edge Scorch on their crop. Tabulated below are a comparison of the results of the analysis with the average values obtained from the trial at NIAB where no symptoms had been observed.

Table 12. Comparison of growing media analysis from nursery with symptomatic plants and 2020 winter trial average.

Sample	mg/l																			
	pH	NH4	NO3	total sol N	P	K	Ca	B	Mg	Cu	Fe	Mn	Zn	S (SO4)	Na	Cl	EC @20c	density (kg/m3)	dry matter %	dry density (kg/m3)
Nursery	6.5	1.1	1.4	2.5	22.2	125.5	4.2	0.46	1.7	0.18	1.04	0.02	0.35	153.3	49.1	36.5	139	285	35.3	100.6
Trial average	5.67	1.39	19.28	20.68	20.83	21.25	32.88	0.35	34.98	0.01	0.53	0.20	0.15	176.14	27.76	17.11	135.42	599.67	44.77	145.50

Some differences were observed in pH, Ca, sodium (Na), Cl, and K, but the latter is not unexpected as the nursery adopts a high K feed in the later stages of the crop. However, none of the values from the nursery sample are of particular concern.

When values from the leaf tissue analysis are compared there are greater differences between NIAB grown material and the grower samples. The level of Ca in the leaf tissue from the nursery sample is higher than in the trials, so it would seem unlikely that the cause of the necrotic leaf tissue is a deficiency of Ca. While the Na in the nursery growing media sample was slightly elevated in comparison with the trial, the Na level in the leaf tissue is substantially higher in the nursery sample by over 900 mg/l. The same order of difference was observed in the values for Cl in the growing media, however standard tissue analysis does not give results for Cl so we do not know if this has also accumulated in the leaf tissue.

Table 18. Comparison of leaf tissue analysis from nursery with symptomatic plants and 2020 winter trial average.

Sample	mg/l																
	pH	NH_4	NO_3	total sol N	P	K	Ca	B	Mg	Cu	Fe	Mn	Zn	S	Na	Mo	Al
Nursery	6.82	200.87	177.67	378.54	411.82	7405	594	2.72	358.53	0.81	2.36	6.62	7.45	341.14	1085.32	0.63	0.34
Trial average	6.91	31.15	410.54	441.69	412.62	5034.62	339.86	2.97	560.17	0.38	1.05	3.98	2.77	191.87	144.53	0.12	0.12

The other difference of note is the level of K which is over 2000 mg/l higher in the nursery sample which could be because of the high proportion of coir in the growing media used which is 70% mix, as well as the high K feed. Also, the difference in the NH_4:NO_3 ratio where the nursery sample has a much higher proportion of NH_4. An excessive amount of K does not appear to have toxic effects, other than to limit the uptake of other nutrient most notably N, and Ca which in this situation would also be a concern. Although K is high in this nursery sample the N and Ca appear unaffected suggesting the levels of K are not detrimental.

It is likely from these results that the cause of the leaf tissue necrosis is not the same as had observed in the experimental trials where symptoms have been seen. The leaf tissue analysis from the grower suggest that this is the result of nutrient toxicity rather than a deficiency; Na is known for its toxic effects and the symptoms are chlorosis of the leaf margin which progresses to necrosis which is the same symptoms that have been investigated in the trial, but also this has similarities to Fe deficiency in its early stages. At no point in our investigation have we observed level of Na that are comparable to those from the leaf tissue at the nursery even where symptoms have been observed, so it can be concluded that these are from different sources.

A potential source of issues is the irrigation water, at the nursery this is stored collect water in winter and spring, and blended mains and stored collected water during summer and autumn.

In Table 14. there is a comparison of water samples taken at NIAB over several years of trial work, and a sample of irrigation water from the nursery taken in May 2018.

Table 14. Comparison of analysis of NIAB irrigation water samples and a nursery irrigation sample.

			mg/l														
SAMPLE	pH	EC µS/cm	Nitrate N	Cl	SO4	P	B	K	Cu	Mg	Mn	Ca	Zn	Na	Fe	Carbonate	Alkalinity as HCO3
Glasshouse irrigation water 2022	7.7	618	9.8	41.9	31	1	0.03	2.5	<0.01	3.87	<0.01	113	<0.01	16.1	<0.01	<10	296
Glasshouse irrigation water 2021	7.7	611	9.8	39	30.8	0.8	0.03	2.7	<0.01	3.74	<0.01	117	<0.01	16.7	<0.01	<10	277
Glasshouse irrigation water 2019	7.5	602	8.8	32.4	28.5	1.1	0.03	2.8	<0.01	3.6	<0.01	118	0.01	12	<0.01	<10	272
Nursery irrigation water May 18	7.6	311	5	15.7	12.5	0.3	<0.01	1.3	0.01	2.06	<0.01	57.1	0.35	7.6	<0.01	<10	150

The analysis gives no obvious cause for the very high levels of Na in the leaf tissue at the nursery site. Other nutrients fall within a similar range to the values at NIAB or are slightly lower which is not unexpected as the nursery uses collected rainwater. This is the likely reason for lower Ca and hardness in the nursery water sample, but when looking at the leaf tissue analysis low Ca was not identified as being deficient.

The two trials reported on here have been carried out over winter, but the trial earlier in 2020 was during the summer to replicate primula production for the early autumn market. The nursery which supplied material for analysis had described symptoms of leaf edge scorch during summer, so it is also important to consider if the symptoms were from other environmental conditions. In investigating Ca nutrition, the rate of water application has been considered in relation to root pressure as well as the role of transpiration, both of which effect nutrient movement. Transpiration has other functions; one is to reduce leaf temperature by the vaporisation of water at the leaf cell level. The leaf temperature is raised by solar radiation and if too high this can impair photosynthesis; where light and sufficient water is available the loss of water through the leaf stomata will cool the leaf tissue. Where plants are under stress from drought, leaf stomata close and transpiration stops, so plants that suffer from a lack of water often exhibit symptoms of thermal stress due to the high leaf temperature the symptoms of which can be necrosis of leaf tissue.

Figure 20. Comparison of different possible causes of necrotic leaf margins, (from left to right) potential nutrient toxicity (possibly Na), thermal stress and potential nutrient deficiency (Ca).

It is possible then that "Leaf Edge Scorch" as described by growers has multiple causes, not just one and in trying to resolve the issue the whole growing environment needs to be considered taking into consideration nutrition, water supply and environment.

Conclusions

- Multiple causes of leaf necrotic tissue have been identified, not all appear to be related to Ca nutrition.
- Reduction of humidity at crop height can increase Ca in leaf tissue, the response is not always consistent but reduction in humidity should be considered as part of a best practice approach to water management and the reduction of disease in a crop.
- Foliar applications at weekly interval of $Ca(NO_3)_2$ at a dilution rate of 1:250 appear to be a beneficial for increasing Ca levels in leaf tissue during winter months.
- Water stress can reduce levels of Ca in the plant but can also be the cause of drought induced thermal stress resulting in necrotic leaf tissue.
- Using a liquid feed once a week with NPK ratio of 21-7-21 + 1.6 MgO + TE made up to a stock solution of 1 kg/10 l and diluted 1:200, is a successful delivery method for autumn winter production.
- To reverse the symptoms of Fe deficiency in the leaves of Primula, apply foliar applications of Fe in the form of a 2% sequestered product at 5 ml in 1 l water at weekly intervals for 4 weeks.

Knowledge and Technology Transfer

ICL Hortscience online event 2021 – video presentation – The effect of calcium nutrition in leaf edge scorch

AHDB Knowledge Library pages:

Leaf edge scorch in Primula

How to prevent leaf edge scorch in Primula

The possible causes of iron deficiency in petunia and primula

Glossary

Macronutrient are types of elements found in fertilisers that a plant requires in large amounts (compared to others) for normal growth. Macronutrients are N, P, K, Mg, Ca & S.

Micronutrients or trace elements are essential elements that are required in smaller amounts than that of macronutrients. Micronutrients are Fe, Mn, B, Mo, Cu & Zn.

Photosynthesis is the process by which green plants, algae and some microbes convert light energy, carbon dioxide and water into energy (glucose) and oxygen. Photosynthesis occurs within the cells chloroplasts and is directly affected by light intensity, carbon dioxide concentration, available water, temperature and the availability of essential nutrients like Mg.

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Collier, G.F. & Tibbitts, T.W. (1984). Effects of relative humidity and root temperature on calcium concentration and tipburn development in lettuce. *Journal of the American Society for Horticultural Science. American Society for Horticultural Science.* 109: 128-31.

Hu, H. & Brown, P.H. (1997) Absorption of boron by plant roots. *Plant and Soil* 193: 49.
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Appendices

Appendix 5. 2020/2021 autumn winter trial data

Table 1. Plant width at trial mid-point

Plant width (mm) 30/11/2020

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	126	142	94	118	102	126	98	110	120	115	90	116
	135	152	99	123	130	128	98	125	122	138	109	125
	136	153	105	132	135	146	104	125	122	141	111	140
	137	153	105	132	136	155	111	131	123	148	112	140
	141	155	105	133	137	158	117	132	124	148	116	142
	142	162	110	135	142	167	118	132	125	159	117	144
	142	167	110	140	145	173	119	132	142	174	117	151
	145	168	113	146	148	176	122	134	142	176	121	155
	146	170	114	147	150	179	122	140	146	180	121	156
	150	170	116	147	150	180	123	143	147	182	123	156
	151	172	122	151	151	180	124	144	148	185	125	156
	155	175	127	152	152	185	124	144	149	187	126	160
	156	180	131	152	153	186	126	154	150	190	127	160
	160	182	131	153	158	187	127	155	152	191	128	161
	160	182	132	156	159	190	127	155	153	192	131	161
	161	183	137	163	160	190	127	157	153	195	132	161
	162	185	138	168	162	200	130	160	153	196	136	164
	162	196	138	170	164	215	132	160	155	202	136	170
	163	198	142	176	166	220	132	164	156	210	136	172
	165	200	143	178	168	225	136	164	158	211	137	175
	166	201	144	179	172		137	167	160	215	145	176
	167	215	146	184	177		137	169	160	215	146	185
	176	215	147	187	177		141	174	162	216	148	196
	183	225	148	197	178		145	180	166	232	151	198
	191	227	163	227	184		149	200	172		156	235
Average	155.1	181.1	126.4	157.8	154.2	178.3	125	150	146.4	183.3	127.9	162.2

Table 2. Plant width at final assessment

Plant width (mm) 25/01/2021

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	219	198	132	155	179	149	135	135	152	181	156	145
	234	212	135	176	185	195	140	156	164	204	160	175
	219	218	149	185	186	215	141	175	170	225	160	210
	204	224	150	202	192	229	142	178	175	239	161	215
	219	235	151	206	194	236	148	178	198	244	165	225
	229	236	151	225	195	236	150	182	199	246	170	225
	201	238	152	225	198	239	150	186	199	254	172	225
	225	245	152	229	199	259	155	208	199	254	175	245
	180	256	152	230	204	265	159	209	200	261	175	250
	199	264	154	240	205	274	161	218	202	276	179	265
	210	264	155	241	206	279	161	219	204	282	180	265
	188	269	156	241	209	284	165	219	204	282	184	265
	215	275	156	245	210	287	166	235	206	283	185	270
	192	284	157	245	213	296	168	248	209	285	185	270
	256	285	158	280	214	299	169	250	213	287	192	280
	215	286	159	285	216	300	171	252	221	292	192	290
	238	298	161	287	216	322	171	259	224	299	195	290
	244	324	164	291	219	334	175	260	226	309	195	300
	224	325	165	291	225	335	175	270	229	317	197	300
	220	329	166	300	226	365	175	280	229	317	200	305
	229	329	171	310	229		178	280	230	325	200	305
	218	336	178	316	231		189	281	234	325	205	310
	291	344	178	318	232		192	285	234	332	205	320
	205	364	178	320	234		196	320	254	334	205	340
	186	375	190	325	241		205		259	348	210	390
									275			
									284			
									295			
									298			
									324			
Average	218	281	159	255	210	270	165	228	224	280	184	267

Table 3. Flower number

Flower number 25/01/2021

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	10	0	6	0	12	0	6	0	5	3	1	0
	11	0	6	0	12	2	7	0	5	3	3	0
	16	4	9	2	14	3	8	3	6	4	5	3
	16	7	9	8	14	5	8	6	11	6	5	4
	17	7	9	8	15	6	8	6	11	6	7	5
	18	7	10	8	15	7	9	6	12	8	7	5
	18	8	10	9	21	8	9	6	12	8	7	5
	18	8	10	9	21	8	9	7	12	8	8	6
	19	8	10	10	21	8	9	8	13	8	8	6
	19	8	10	10	21	10	9	9	13	8	9	7
	20	9	11	10	22	12	10	9	13	9	10	7
	20	9	11	10	22	13	10	10	13	10	10	8
	20	10	11	10	22	13	10	10	13	10	10	9
	20	10	11	10	23	13	10	10	13	10	10	9
	22	11	12	11	23	13	11	10	13	10	11	9
	22	12	12	11	25	15	11	11	13	10	11	10
	24	16	12	11	26	16	11	11	13	10	11	10
	24	17	12	11	26	19	11	11	14	11	11	10
	25	17	12	11	27	20	11	11	14	11	12	11
	25	17	12	11	28	24	12	12	14	11	12	11
	25	19	12	12	29		12	12	14	12	12	11
	26	20	13	12	30		12	12	14	13	13	12
	26	20	13	13	30		15	13	14	14	14	12
	30	20	15	14	32		20	13	15	15	16	13
	31	22	16	27	36		22	14	15	16	23	14
									16			
									17			
									23			
									23			
									25			
Average	20.9	11.4	11	9.92	22.7	10.8	10.8	8.8	13.6	9.36	9.84	7.88

Table 4. Fresh weight of above ground growth

Fresh weight of above ground growth (g) 25/01/2021

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Values	14.76	5.16	7.46	5.8	12.48	5.66	7.54	5.48	12.55	6.76	9.07	3.76
	18.16	8.35	8.15	8.57	15	9.44	8.3	9.02	14.08	8.28	9.9	6.49
	19.68	8.63	8.15	9.28	16.15	10.19	8.91	9.41	14.7	11.39	11.07	9.38
	20.35	11.52	8.51	10.05	16.5	10.32	9.55	9.48	16.46	11.56	11.24	9.85
	20.48	12.21	8.89	11.6	17.61	12	9.83	9.5	16.59	12.22	11.62	10.35
	20.6	12.39	8.95	12.67	18.06	13	10.19	11.84	16.67	14.05	11.73	12.27
	20.79	12.49	9.04	14.08	18.69	15.7	10.28	12.46	17	15.17	11.81	13.25
	21.26	12.69	9.23	14.76	18.77	16.78	10.48	13	17.43	15.5	11.98	13.89
	21.4	14.09	9.56	14.92	18.79	17.93	10.84	13.68	17.49	16.44	12.37	15.13
	21.54	15.91	9.62	15.87	19.05	19.36	10.88	14.79	18.09	16.59	12.56	15.32
	22.24	16.92	9.67	17	20	21.94	11	15.09	18.22	16.79	12.66	15.63
	22.56	17.74	9.96	17.26	20.13	22.29	11.03	15.16	18.47	18.76	12.67	16.42
	23	19.26	10	17.89	20.31	22.38	11.43	15.63	18.66	19.04	12.76	16.48
	23.11	20.15	10.16	18.46	20.51	24.13	11.45	16.1	18.7	19.13	13.24	17.13
	23.41	21.85	10.17	18.94	21.45	24.14	11.52	16.46	18.97	19.55	13.32	18.08
	23.5	23.31	10.42	19.03	21.53	25.54	11.68	16.69	19.09	19.7	13.75	19.73
	23.79	26.25	10.48	20.79	22.05	26.94	11.97	17.11	19.12	20.44	13.78	19.9
	23.96	26.63	10.76	21.11	24.14	28.55	12	17.25	19.38	20.67	13.8	21.61
	24.46	27.44	10.84	21.38	24.37	34.53	12.88	17.34	19.42	21.3	13.86	21.83
	24.87	27.48	11.16	21.64	24.81		13.36	17.6	19.51	22.11	13.87	22.78
	25.42	28.35	11.16	22	25.08		13.87	18.49	20.07	24.06	14.38	24
	26.2	31.58	11.96	23.82	26.47		14.06	19.17	20.39	25.22	14.73	25.26
	27.1	32.62	12.51	24	26.68		14.2	19.78	20.57	26.22	14.84	26.62
	28.52	36.88	12.97	27.67	28.87		14.78	19.82	21	28.11	14.96	28.53
	29.62	38.14	13.09	35.58	29.24		15.53	24.43	21.4	28.68	15.54	29.17
									22.24		15.91	
									22.67			
									25.21			
									26.16			
									27.92			
Average	22.83	20.32	10.11	17.77	21.07	18.99	11.5	14.99	19.27	18.31	12.98	17.31

Appendix 6. 2020/2021 autumn winter leaf tissue and growing media laboratory analysis

Table 1. Growing media analysis, sampled 25/01/2021

Description of treatment				RESULTS (mg/l)																			
Treatment number	water	humidity	Calcium nitrate rate	pH	EC @20c	density (kg/m3)	dry matter	dry density (kg/m3	Cl	P	K	Mg	Ca	Na	NH4	NO3	total sol N	S (SO4)	B	Cu	Mn	Zn	Fe
T1	High	low	none	6.1	67	713	22.4	159.7	17	10.4	8.8	11.3	18	20.8	1.1	1.3	2.5	89	0.44	<0.01	<0.01	0.15	0.32
T2	High	high	none	5.9	59	699	22.3	155.9	16.2	6.5	12.7	9.2	13.7	19.4	1.4	9.1	10.5	50.4	0.37	<0.01	<0.01	0.11	0.26
T3	Low	low	none	5.3	234	370	40.7	150.6	27.1	34.1	47.4	67.6	50.4	39.3	1.1	37.5	38.6	312.8	0.31	<0.01	0.31	0.12	0.97
T4	Low	high	none	5.6	106	616	24.8	152.8	13	14.2	13.2	23.7	26.7	24.6	<0.6	14.2	16.6	140.3	0.47	<0.01	0.07	0.12	0.43
T5	High	low	1:500	5.8	94	533	27	143.9	11.8	14.9	6.1	23.3	25.7	20.6	1.2	2.4	3.5	155.4	0.34	<0.01	0.06	0.14	0.45
T6	High	high	1:500	6	55	688	22.5	154.8	17.2	6.2	11.3	6.3	12	21.5	1.5	8.7	10.2	40	0.31	<0.01	<0.01	0.13	0.28
T7	Low	low	1:500	5.3	350	389	35.7	138.9	32.3	60.2	57.2	114.9	85.3	44.9	1.4	62.5	63.9	484.8	0.36	0.01	0.56	0.25	1.2
T8	Low	high	1:500	5.5	179	679	23.6	60.2	12.9	24	34.4	42.3	41.3	33.5	2.8	42.4	45.2	177.3	0.3	0.01	0.16	0.17	0.45
T9	High	low	1:1000	5.7	104	649	238	154.5	11.6	19.5	9.2	25.8	29.4	22	1.1	5.4	6.5	154.8	0.29	<0.01	0.06	0.15	0.43
T10	High	high	1:1000	5.9	59	726	23.3	169.2	13.7	6.6	13	7.1	12.6	19.5	1.1	10	11.2	37.1	0.3	<0.01	<0.01	0.11	0.22
T11	Low	low	1:1000	5.4	208	430	34.7	149.2	18.6	37.4	26.7	63.4	52.6	37.5	<0.6	21.7	22.3	329	0.33	<0.01	0.29	0.15	0.9
T12	Low	high	1:1000	5.5	110	704	22.2	156.3	13.9	15.9	15	24.9	26.8	29.5	1.2	16.1	17.2	142.8	0.43	<0.01	0.07	0.14	0.46

Table 2. Primula leaf tissue SAP analysis sampled 25/01/2021

Description of treatment				RESULTS (mg/l)															
Treatment number	water	humidity	Calcium nitrate rate	PH	NH4	NO3	Al	B	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
T1	High	low	none	6.83	24.98	530.52	0.05	3.47	348.3	0.43	0.69	4397.21	521.18	3.04	0.22	139.91	361.48	112.74	2.25
T2	High	high	none	6.96	41.27	324.5	0.16	1.31	522.64	0.27	1.09	6542.06	868.46	7.85	0.13	244.3	501.63	375.34	3.04
T3	Low	low	none	6.94	28.39	839.94	0.07	3.15	281.5	0.36	0.51	5607.07	513.74	3.55	0.1	105.52	392.22	139.14	2.12
T4	Low	high	none	6.78	19.81	50.19	0.12	3.06	424.29	0.31	1.12	3537.26	635.55	4.43	0.1	149.67	368.72	242.63	2.49
T5	High	low	1:500	6.88	27.18	485.8	0.07	3.41	326.04	0.41	0.88	4539.62	444.66	2.94	0.13	123.19	345.68	143.12	2.62
T6	High	high	1:500	7.04	46.74	267.03	0.16	2.41	367.41	0.35	1.48	5747.06	613.17	4.49	0.08	166.79	466.44	288.89	3.78
T7	Low	low	1:500	6.97	37.55	758.74	0.07	3.31	233.75	0.42	0.62	5892.21	430.29	2.87	0.07	114.24	447.21	137.59	2.57
T8	Low	high	1:500	6.87	28.03	112.12	0.16	3.65	379.02	0.37	0.76	4638.52	662.26	4.49	0.07	149.16	440.6	249.22	2.93
T9	High	low	1:1000	6.83	29.38	584.76	0.06	3.37	302.48	0.45	0.93	5211.15	529.75	3.13	0.07	147.86	429.85	125.73	2.51
T10	High	high	1:1000	7	37.97	314.41	0.16	2.25	274.13	0.25	1.2	5262.9	514.92	3.56	0.07	135.93	408.33	196.02	3.33
T11	Low	low	1:1000	6.9	29.05	442.84	0.11	3.03	195.69	0.35	0.78	4468.06	359.87	2.3	0.05	90.15	365.12	105.4	2.82
T12	Low	high	1:1000	6.86	23.44	215.61	0.28	3.21	423.09	0.56	2.53	4572.31	628.19	5.07	0.31	167.65	424.2	186.62	2.74

Appendix 7. 2020/2021 autumn winter trial images

Images dated 27/10/2020

		
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9

		
Treatment 10	Treatment 11	Treatment12

Appendix 8. 2020/2021 autumn winter environmental data monitored at crop leaf height using Blue Maestro Tempo Disc™ 3 in 1 Bluetooth environmental monitors

	Low water Low humidity	**Low water High humidity**	**High water Low humidity**	**High water High humidity**
Average temperature ºC	11.5	10.9	11.0	13.9
Average humidity %	59.1	67.7	64.7	90.3

Appendix 9. 2021/2022 autumn winter trial data

Table 1. Plant width

Plant width (mm) 15/02/2022

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Values	240	180	130	210	150	235	150	180	185	170	150	240	170	180	145	170
	230	190	160	185	180	170	160	100	220	200	175	160	175	185	185	240
	220	200	145	165	230	165	150	230	175	170	200	240	210	210	165	270
	240	220	180	170	170	225	150	225	150	150	140	250	180	200	160	250
	230	190	140	145	170	235	210	220	165	220	205	200	180	200	185	200
	190	185	145	190	175	220	135	215	200	210	190	240	175	100	180	210
	220	210	125	180	180	150	150	190	180	200	170	165	170	175	190	125
	200	240	170	115	195	190	145	185	165	250	150	135	190	210	150	200
	230	230	160	175	180	200	170	175	180	190	165	180	190	220	210	190
	260	200	125	165	150	210	145	200	160	200	155	155	210	180	215	280
	210	190	150	180	190	215	135	150	190	185	160	150	120	170	170	205
	240	190	145	175	155	280	165	190	200	210	160	190	180	185	190	260
	230	180	175	185	160	250	130	155	180	200	170	185	190	260	190	280
	240	155	130	170	180	200	180	190	190	220	165	210	165	210	170	240
	210	210	150	140	155	195	150	220	185	210	145	190	180	270	220	220
	215	240	140	150	190	200	145	160	175	210	125	190	170	230	200	215
	230	220	140	205	170	190	160	165	115	140	235	200	130	225	190	250
	190	215	130	190	175	210	135	210	120	250	160	195	175	180	190	270
	150	215	150	135	150	180	160	195	160	205	130	210	115	195	150	260
	170	185	140	150	180	200	180	200	210	180	160	170	200	240	145	210
	165	220	120	210	190	220	165	210	200	180	180	210	180	185	210	200
	230	190	170	190	195	180	140	205	210	215	165	195	170	210	215	195
	215	180	180	175	180	180	145	210	205	200	150	215	175	150	195	190
	210	205	140	180	210	220	185	195	210	210	160	240	170	230	180	200
	245	175	190	195	175	0	180	210	230	180	120	245	160	250	225	230
Average	216.4	200.6	149.2	173.2	177.4	196.8	156.8	191.4	182.4	198.2	163.4	198.4	173.2	202	185	222.4

Table 2. Number of Flowers

Number of flowers 15/02/2022

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Values	0	0	0	0	0	1	0	0	2	1	0	0	2	0	0	0
	4	1	2	0	3	0	0	0	2	0	1	0	3	0	0	0
	0	2	0	0	0	0	2	0	0	1	0	1	1	2	0	0
	3	0	0	0	0	3	0	0	0	0	0	4	1	1	0	1
	0	0	0	0	0	1	1	0	0	0	0	0	2	0	3	0
	1	0	0	0	1	1	0	0	2	5	0	0	0	0	0	0
	0	0	0	0	2	0	0	1	1	5	0	1	0	0	1	0
	1	0	0	0	1	0	0	0	1	3	0	0	0	2	0	0
	1	1	1	3	0	0	2	1	2	0	2	1	0	2	3	0
	6	2	0	0	2	0	0	0	0	0	2	0	0	1	0	2
	0	0	0	0	3	3	0	1	1	3	0	2	0	0	0	0
	1	0	1	0	0	3	0	0	0	0	0	4	1	0	0	2
	1	0	0	0	3	3	0	0	0	0	0	0	2	2	3	3
	2	0	1	1	1	2	0	0	1	0	0	0	0	1	1	0
	1	2	0	0	1	0	0	0	3	1	0	0	0	2	0	0
	4	2	0	3	0	5	0	0	1	3	0	0	1	1	1	2
	0	0	2	1	3	0	1	0	2	0	0	1	0	0	1	2
	0	0	0	0	3	0	3	2	0	1	0	0	2	1	0	0
	0	1	2	0	0	0	2	2	0	0	0	0	1	0	0	1
	0	0	0	0	3	0	0	2	0	0	3	0	0	0	0	2
	1	3	0	3	3	0	0	0	2	0	0	0	0	0	0	0
	3	0	2	1	1	0	0	0	4	0	0	0	1	0	1	0
	1	1	0	0	0	1	0	2	0	1	0	0	0	0	0	1
	0	1	0	2	0	2	0	0	3	2	2	0	1	2	1	1
	1	0	0	2	1		2	0	3	1	1	5	0	2	1	2
Average	1.24	0.64	0.44	0.64	1.24	1.042	0.52	0.44	1.2	1.08	0.44	0.76	0.72	0.76	0.64	0.76

Table 3. Weight of above ground growth

Fresh weight of above ground growth (g) 15/02/2022

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Values	18.51	18.58	9.03	17.33	13.43	26.62	14.55	16.07	14.18	18.67	9.64	23.66	15.26	18	10	18
	30.78	20.64	11.41	12.46	18.13	17.81	13.69	4.68	13.87	20.85	18.09	15.51	21.13	24	15.6	25.61
	17.26	21.31	9.09	11.71	23.97	22.14	11.75	22.48	10.16	20.62	17.62	26.17	22	20.92	17.09	20.48
	26.14	13.22	17.66	9.31	12.58	25.41	13.51	24.16	17.15	24.52	11.45	25.64	22.3	16.56	20.16	14.65
	27.33	23.78	9.87	19.3	19.34	24.4	20.2	22.4	16.14	23.96	14	24.76	20.73	7.36	14.82	22.83
	14.53	18.8	9.67	15.86	17.81	25.42	11.07	14	8.25	14.95	13.75	23.21	20.18	22.35	7.48	24.67
	19.43	23.86	12.39	9.77	15.18	23.17	10.7	18.49	25	24.32	11.04	22.79	16.21	20.07	15.26	23.73
	20.6	15.18	10.62	20.44	16.38	19.63	12.29	21.68	25.55	20.5	12.38	15.7	19.14	27.67	14.7	17.89
	19.22	20.64	9.95	17.36	19.14	26.78	9.38	18.04	16.29	24.08	14.21	17	13.9	20.04	17.81	18.22
	33.3	15.88	9.77	11.9	20.3	30.52	9	20.46	17.31	19.19	12.66	18.62	12.79	20.6	13.72	9.42
	23.74	21.28	12.66	20.1	19.24	28.87	10.44	12.03	18.86	15.74	17.48	17.15	11.41	23.15	11.43	19.3
	27.19	19.27	11.5	19	17.26	17.19	13.95	19.05	21.88	22.88	12.8	24.38	17.93	22.7	10.88	29.67
	27.52	9.39	8	15.77	19.97	22.29	14.9	13.56	13.22	22.43	14.22	16.08	15.52	29.62	14.86	26.22
	21.95	29.84	10.55	11.81	9.92	27.21	8.09	21.63	7.08	19.96	15.18	19.76	17.48	27.96	16.36	24.17
	23.3	19	9	14.5	21.74	9.79	9.84	21.95	14	13.24	10.44	21.72	13.8	18.59	17.2	21
	21.89	20.48	8.72	14.32	15.97	19.81	9.65	17.12	9.72	24.28	22	17.7	20.44	21.49	15.58	20.94
	26.48	18.28	6.87	20.25	13.02	19.34	12.97	19.58	17.38	23	14.57	14	17.85	22.45	12.42	25.04
	22.33	22.64	9.77	10.07	16.55	22.15	14.8	14.25	9.6	28	13.18	20.69	15.94	21.74	19.55	21.86
	9.67	16.44	15.67	14.23	18.14	27.5	15.72	22.29	23.93	15.51	14.28	30.15	14.15	19.51	16.53	28.07
	21.97	21.14	13.53	21.44	17.7	23.48	12.3	20.36	17.23	18.41	14.06	22.46	19.19	28.56	8.38	25.3
	13.41	12.84	7.05	20.31	20.6	17.4	13.05	17.38	17.13	15.89	19.87	21.72	16.13	13.7	15.88	24.1
	29.88	20.37	9.88	13.85	18.18	9.16	10.76	14.72	22.73	19.56	12.97	21.74	20.24	13.39	18.71	25.72
	24.8	23.81	8.58	13.34	22.49	23.31	12.98	16.49	17.51	15.43	16.56	22.95	11.81	21.72	18.73	22.51
	21.38	26.48	15.38	15.47	21		11.67	14.73	21.64	23.4	13.12	21.86	20.04	19.06	17.09	23.74
	27.88	22.39	10.53	16.82	17.66		12.78	14.32	22.35	26.76	16.17	23.67	9.08	23.04	13.83	27.42
Average	22.82	19.82	10.69	15.47	17.83	22.15	12.4	17.68	16.73	20.65	14.47	21.16	16.99	20.97	14.96	22.42

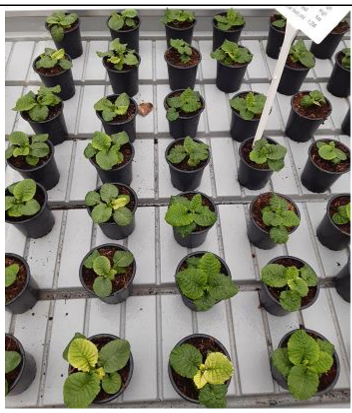
Appendix 10. 2021/2022 autumn winter leaf tissue laboratory analysis

Table 1. Leaf tissue analysis, sampled 15/02/2022

Treatment number	Decription of treatment: water	humidity	Calcium nitrate rate	Results (mg/l): PH	NH_4	NO_3	Al	B	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
T1	High	low	none	6.56	28.26	121.18	0.17	4.80	423	0.56	1.79	4898	471.44	3.53	0.17	239.53	370.62	209.29	3.95
T2	High	high	none	6.64	32.10	251.87	0.13	5.27	370	0.49	1.70	5645	394.55	3.07	0.11	201.21	398.71	175.40	3.67
T3	Low	low	none	6.62	36.08	51.82	0.28	3.93	595	0.61	2.29	5510	706.23	5.38	0.24	318.31	339.36	350.90	3.73
T4	Low	high	none	6.67	46.25	396.19	0.17	4.40	444	0.74	1.67	6820	631.80	4.35	0.16	276.81	440.35	273.38	3.53
T5	High	low	1:250	6.62	45.96	179.85	0.14	4.61	423	0.57	1.34	5440	480.08	2.81	0.09	222.05	364.56	276.06	3.58
T6	High	high	1:250	6.60	37.36	245.20	0.34	5.41	361	0.73	1.47	5183	379.89	2.55	0.09	153.08	328.60	156.73	3.86
T7	Low	low	1:250	6.52	42.02	128.42	0.22	3.26	704	0.54	1.77	5458	719.76	4.15	0.11	300.79	335.58	324.60	3.00
T8	Low	high	1:250	6.58	48.65	504.71	0.35	5.34	545	0.78	2.16	6917	580.98	3.97	0.10	229.62	555.58	264.85	4.44
T9	High	low	1:500	6.82	47.53	100.37	0.32	5.16	432	0.53	1.30	5112	501.91	3.23	0.15	202.00	348.56	309.50	4.11
T10	High	high	1:500	6.81	38.78	169.47	0.25	6.32	349	0.46	1.22	5485	386.92	3.04	0.19	156.24	394.56	204.42	3.95
T11	Low	low	1:500	6.70	59.09	114.21	0.27	4.31	626	0.49	1.65	6021	751.74	4.49	0.54	324.25	460.35	509.60	4.18
T12	Low	high	1:500	6.81	49.71	419.05	0.15	5.36	422	0.61	1.14	6294	532.09	3.96	0.21	201.92	499.43	259.30	3.67
T13	High	low	1:1000	6.80	67.03	80.34	0.20	5.56	394	0.46	1.14	5776	550.75	3.28	0.15	220.40	388.59	309.63	4.15
T14	High	high	1:1000	6.84	68.36	247.12	0.24	6.60	453	0.72	1.36	6741	580.52	4.31	0.16	208.10	563.97	251.33	4.34
T15	Low	low	1:1000	6.95	75.03	224.96	0.26	4.83	534	0.51	1.47	6511	708.95	4.78	0.18	329.94	415.45	347.39	4.06
T16	Low	high	1:1000	6.82	62.54	360.42	0.20	5.65	301	0.48	1.05	5514	403.59	2.91	0.12	146.84	438.22	168.58	3.41

Appendix 11. 2021/2022 autumn winter trial images

Trial images dated 15/11/2021

		
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9

		
Treatment 10	Treatment 11	Treatment12
		
Treatment 13	Treatment 14	Treatment 15
		
Treatment 16		

Trial images dated 15/02/2022

	
Treatment 1	Treatment 2
	
Treatment 3	Treatment 4
	
Treatment 5	Treatment 6
	
Treatment 7	Treatment 8
	
Treatment 9	Treatment 10

	
Treatment 11	Treatment 12
	
Treatment 13	Treatment 14
	
Treatment 15	Treatment 16

Appendix 12. Environmental data.

Table 1 2021/2022 autumn winter environmental data monitored at crop leaf height using Blue Maestro Tempo Disc™ 3 in 1 Bluetooth environmental monitors

	Low water Low humidity	Low water High humidity	High water Low humidity	High water High humidity
Average temperature ºC	7.8	7.8	8.0	8.7
Average humidity %	47.1	60.0	48.2	79.3

Introduction – Section 3. Determine best practice for managing N application to field-grown narcissus in relation to stem length, base rot and Nitrate Vulnerable Zone (NVZ) restrictions

Narcissus is a significant field crop in the UK for both cut flower and bulb production with 3808 ha per annum (figures in 2019), the main areas of production in Cornwall, Lincolnshire and the Grampian region of Scotland. The nutrient management recommendations for bulbs and bulb flowers are contained within the 8th edition of RB209 (2010) and include revisions from the 7th edition based on industry consultation, these were in turn presented within the AHDB Horticultural Narcissus Manual (Hanks, 2013) along with the previous research on which the recommendations were based. Since then, the only research into nutrient management for this crop is the AHDB funded project CP 103 (Lillywhite, R. 2016) which looked at N fertilisation in narcissus but only made conclusions about placement, not rates.

Declining prices for bulbs in recent years have changed grower practices, with more focus on longer cut flower production from a single planting of bulbs. Cut flower crops are now in the ground anywhere from 3 to 7 years depending on variety and sensitivity to basal rot (*Fusarium oxysporum* f.sp. *narcissi* (FON)), previously most cut flower crops will have been lifted after 3 years for sale of bulbs.

Most growers are planting crops into a rotation containing agricultural crops such as potato, brassica, barley and peas, and frequently no base dressing of N is applied. Currently the timing of application of N for this crop is limited by Nitrate Vulnerable Zone (NVZ) restrictions which cover about 55% of land in England, for which the closed period is 1st September to 15th January. As narcissus is an early flowering crop, its winter growth is highly important to its flowering productivity.

When consulted nearly 38% of the growers consulted reported that there was no application of N during the lifetime of the crop, so subsequently the same percentage of respondents said they would not benefit from a NVZ application exemption. The 60%+ that do apply N all felt they would benefit from being able to apply during the NVZ closed period. However, these growers did all also comment that they believed that they see a link between N application and FON or basal rot. FON is an important disease of this crop which causes loss in the field and in storage, high temperature in both soil and storage are known to exacerbate the development of the disease and crop management practices are designed to limit exposure. As investigated in other crops such as onion, increased N appears to give increased incidence of disease in narcissus which could be linked with increased softness of the bulb with excessive N fertility.

Figures gathered by the AHDB have shown that in the period May 2021 to May 2022, the price of UK-produced ammonium nitrate (NH_4NO_3) fertiliser in Great Britain had increased by 152% and imported prices had increased by 171%. Targeted application of N to all crops is of paramount importance for financial viability, particularly where there is little scope for product price increases.

The trials were designed to investigate the application of N as a top dressing in field grown narcissus, taking the current guidance into consideration but also looking at the effect on yield versus incidence of basal rot caused by FON. The trial also investigated if timing of applications can improve yield, with a specific aim to see if there was justification for application in the current NVZ closed period.

Materials and methods

Two sites were chosen from different growing areas to investigate application rates in different soil type, and different harvesting dates.

Sites were chosen in Cornwall and Lincolnshire where the trials took place over 3 years on a single planting of bulbs at each site.

Details of the two sites are as follows:

1. Lincolnshire trial host: Jack Buck Farms
    - Location: Moulton, Spalding, Lincolnshire
    - Planting year: 2019
    - Variety: Tamsyn
    - Previous cropping: vining peas
    - Fertiliser: 0:100:300 kg/ha applied
    - Aspect: level
    - Soil: Loamy and clayey soils with naturally high groundwater

Figure 21. Lincolnshire trial site, image date 16/11/2020.

2. Cornwall trial host: Greenyard Flowers
    - Location: Trispen, Truro
    - Planting year: 2019
    - Variety: Karenza
    - Previous cropping: Potatoes
    - Fertiliser: None applied
    - Aspect: gentle slope, north facing
    - Soil: Freely draining slightly acid loam

Figure 22. Cornwall trial site, image dated 06/01/2021.

Full results from soil analysis carried out at the sites are included in Tables 1 and 2 of Appendix 13 of the report.

At each site the trial consisted of 8 treatments replicated 4 times giving a total of 32 plots in randomised design which remained consistent over the 3 years. The plot size was 2 rows x 12m with a buffer zone of 2 rows between plots to ensure that was no influence from the other plots.

Prior to flowering in year 1, all treatment was according to the host grower's normal agronomic practice. In year 2 and 3 the amount and timing of N application was varied according to the details in Table 15. The timing of application at leaf emergence was anticipated to be at different times at the two sites, reflecting the difference in flowering period for the two areas. For both areas it was anticipated that in a normal flowering year this would fall within the NVZ closed period.

N was applied in the form of a liquid product, Efficie-N-t-28 (28-0-0), using a knapsack sprayer with water application rate 300l/ha.

In all other respects the trial area underwent the same agronomic practices as was standard for the grower, including harvesting and application of sprays.

Table 15. Treatment list with application rate and timing

Treatment	Application rate of N	Application timing	Year 2 application dates		Year 3 application dates	
			Cornwall	Lincolnshire	Cornwall	Lincolnshire
A	30 kg/ha	at leaf emergence	06/01/21	16/11/20	05/01/22	25/11/21
B	50 kg/ha	at leaf emergence	06/01/21	16/11/20	05/01/22	25/11/21
C	80 kg/ha	At leaf emergence	06/01/21	16/11/20	05/01/22	25/11/21
D	30 kg/ha	after 15th January	17/01/21	18/01/21	18/01/22	26/01/22
E	50 kg/ha	after 15th January	17/01/21	18/01/21	18/01/22	26/01/22
F	80 kg/ha	after 15th January	17/01/21	18/01/21	18/01/22	26/01/22
G	controlled release product *	product recommended rate	Delayed	Delayed	n/a	n/a
H	None					

*Composition to be defined in discussion with industry partners.

For treatment G an appropriate product was not identified and sourced in time for application in year 2, so the decision had to be made to remove the controlled release product form the scope of the trial.

All observations were made at the time that picking would normally occur, but before picking commenced. In year 1, base line observations were taken to compare the data obtained in years 2 and 3. In years 1 and 2 observations were made on 25 bulbs per plot on stem length (measured from the point of emergence to base of the flower bud, at the stage the spathe starts to split), number of flower stems per bulb in the Lincolnshire trial. To assess flower yield in the Cornwall trial, observations were made on number of flowers per m length of plot and expressed as a population. This was because of the work being carried out as a combined trial with other work at the same site in order to align observations.

In addition to this in year 3, bulbs from a 2m section of a row were lifted from each plot and scored for symptoms of basal rot and measurement of fresh weight. In the Lincolnshire trial the extended period of dry weather experienced in 2022 made the lifting of bulbs by hand exceptionally difficult, due to this it was agreed that the destructive measurements would be carried out on a 1 m length of plot. In the Cornwall trial, rainfall in the spring meant that the assessments could still be carried out on the originally planned 2 m plot length.

Results

The results are presented for the 2 trial sites individually as there are different factors at both locations that may have influenced the outcome of the trials. The full data set and output of the statistical analysis are included in Tables 1 to 6 of Appendix 14 of the report.

In the case of both the stem length and the population/stem number counts the base line records (year 1 data) for each of the plots has been included for visual comparison, but this is not part of the statistical analysis as there should be no treatment effect. In all cases both treatments G and H can be considered as control plots as the intended applications for G did not go ahead.

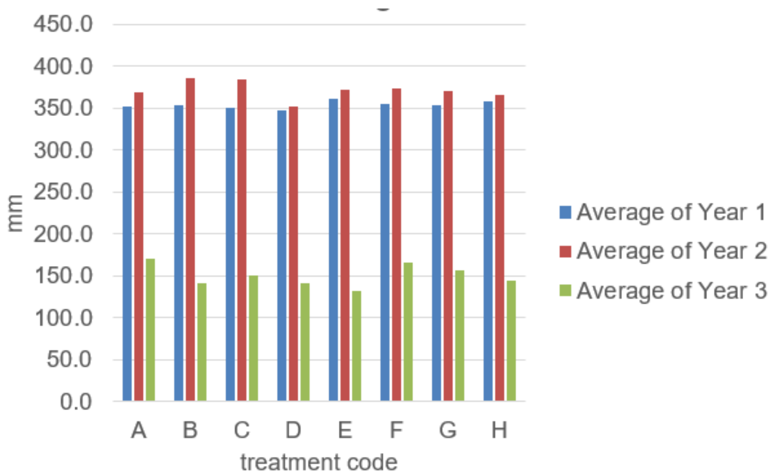


Figure 23. Results of observations on stem length (mm) for Lincolnshire trial for year 1 (2020 baseline), year 2 (2021) and year 3 (2022), L.S.D between treatment 38.23 mm.

No significant differences were observed between treatments in respect to stem length. In year 2 there is a slight increase in stem length with increase in rate of N application, but this is not significant, and this trend does not persist in year 3.

There is a very big seasonal affect for stem length, with the length in year 3 being at least half of that observed in year 1 and 2, suggesting the environment is having a greater impact than the N application.

In year 2 there is a slight increase in length of stem when N is applied at leaf emergence compared to after the NVZ closed period, across all rates but again this is not statistically significant.

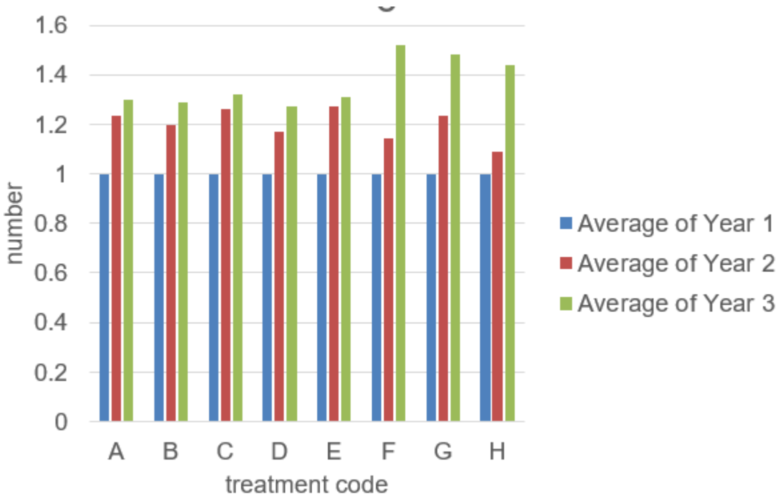


Figure 24. Results of observations on number of stems per bulb for Lincolnshire trial for year 1 (2020 baseline), year 2 (2021) and year 3 (2022). L.S.D between treatments 0.252.

No significant differences were observed between treatments with respect to number of stems, and there seems little pattern in the response to N application on the number of stems produced per bulb, for example in year 2 treatment F is the lowest and in year 3 it is the highest. It is also of note that the results from the control plots fall within the range of expression for the treatment plots in both years.

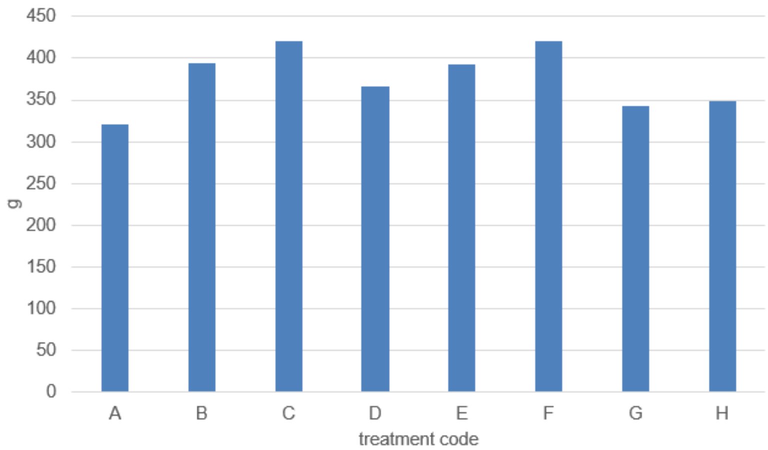


Figure 25. Results of fresh weight of bulb per 1 m section of plot for Lincolnshire trial, observations dated 15/06/2022. L.S.D between treatments 65.12 g.

The observations show that the average weight of bulbs does increase with increasing amount of N when it is applied at leaf emergence or after the NVZ closed period. However, application of N at 30 kg/ha or at 50 kg/ha rate does not significantly increase the weight of bulbs over no application in either period.

Application of N at 80 kg/ha rate does significantly increases the weight of bulbs over no application, at both leaf emergence and after the NVZ closed period, but there is no significant increase from the change in the timing of application from after the NVZ closed period to the point at which the leaves emerge, which was during the NVZ closed period.

Although not significantly different from the bulb weight of the controls, there is a significant difference between the weight of bulbs in the treatments with N applied at 30 compared with the 50 kg/ha rate when applied at leaf emergence.

As there are no significance in the number of bulbs between any treatment, we can be confident that it is an increase in the individual bulb size.

The data obtained on incidence of disease in the Lincolnshire trial shows lower expression of FON than anticipated.

Table 16. Counts of the number of bulbs expressing symptoms of FON, where score of 1 no disease symptoms on an individual bulb and 5 is a high level.

Treatment code	A	B	C	D	E	F	G	H
Application rate	30 kg/ha	50 kg/ha	80 kg/ha	30 kg/ha	50 kg/ha	80 kg/ha	None	None
Application period	at leaf emergence			after 15th January			N/A	
Number of bulbs at disease score								
1	370	465	381	423	439	464	427	401
2	1	2	4	6	4	1	3	2
3	2	2	2	0	0	0	0	0
4	1	0	0	0	0	1	1	1
5	1	0	0	0	0	0	0	0

On initial inspection the data seemed to suggest that the application of N at leaf emergence increased the rate of disease above that seen in the treatments with no N applied, or those with N applied later. However, the total number of affected bulbs is the same for both application periods, and there is minimal difference in the severity. There is also little difference between the plots where N is applied and the untreated control plots. The large number of null values obtained make for poor statistical analysis, so it is not possible to say if these minor differences have any significance.

The Cornwall observations have been transformed from the original measurements in cm to mm to aid comparison with the Lincolnshire trials.

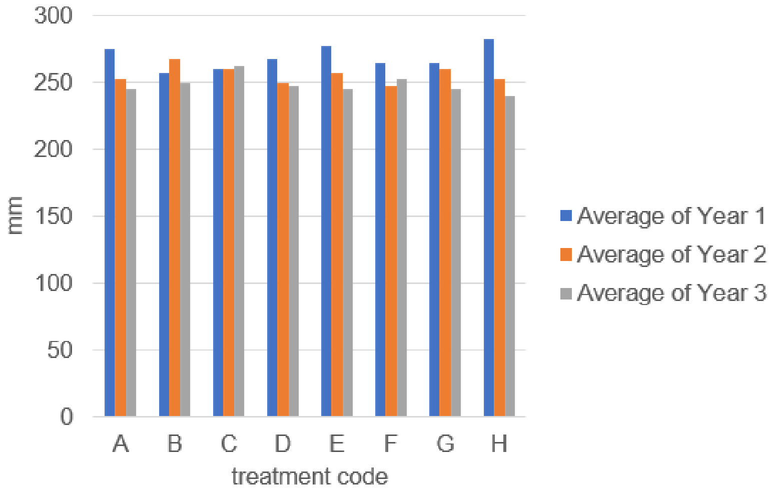


Figure 26. Results of observations on stem length (mm) for Cornwall trial for year 1 (2020 baseline), year 2 (2021) and year 3 (2022). L.S.D between treatments 33.09 mm

Very little variation is observed either between years or between treatments, and none of the variation seen represents significant differences.

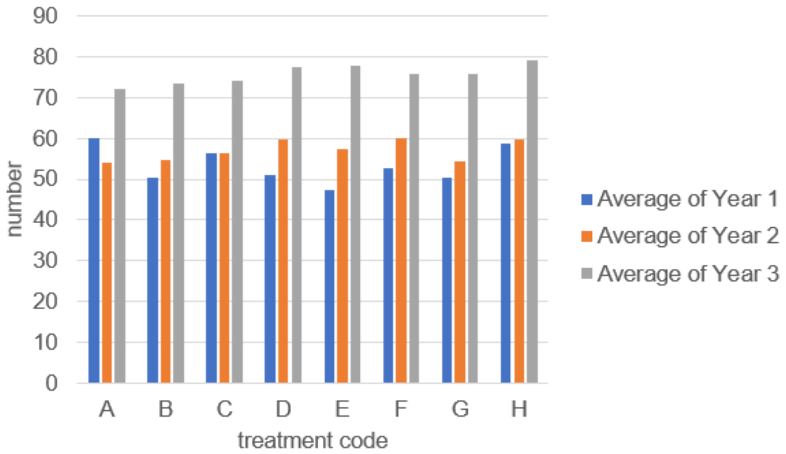


Figure 27. Results of observations on number of stems per 1 m of plot for Cornwall trial for year 1 (2020 baseline), year 2 (2021) and year 3 (2022). L.S.D between treatments 10.649

No significant differences between treatments in the number of stems observed per 1 m length of plot. The trend is for the number of stems to increase over the period of the trial, but the values obtained all move similarly suggesting that this is related more to the general environment or the age of the bulb.

There is a slight suggestion for the number to be slightly higher when N is applied after the NVZ closed period than at leaf emergence, but to reiterate these differences are not significant.

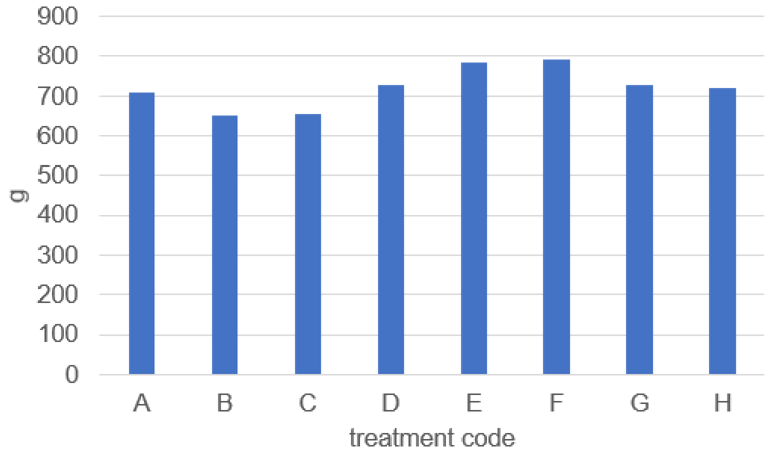


Figure 28. Results of fresh weight of bulb per 2 m section of plot for Cornwall trial, observations dated 26/05/2022. L.S.D between treatments 48.81 g.

The results show that the average weight of bulbs does increase with increasing rate of N, but only where it is applied after the NVZ closed period, no increase with rate is seen when the application is at leaf emergence.

The application of N at 30 kg/ha rate does not significantly increase the weight of bulbs over no application, either at leaf emergence or after the NVZ closed period. Application of N at 50 kg/ha rate and at the 80 kg/ha rate does significantly increase the weight of bulbs over no application after the NVZ closed period, but not when applied at leaf emergence.

Application of N at the 2 higher rates at leaf emergence has given rise to a significantly lower fresh weight of bulbs when compared with application after the NVZ closed period. At the lowest rate there is no significant difference. It is unclear why this might be the case as there is no significant incidence of basal rot in the trial to cause loss of bulbs in these treatments. Basal rot was in fact only seen in a single bulb in each of 4 plots, each of a different treatment.

Discussion

The investigation in this trial fell into 3 main aspects, timing of application, rate of application, and impact of rate on incidence of FON. In discussing the results, it is important to consider that the 2 trial sites were picked for their different geographical position, and in doing that different varieties have been used at each site due to availability of suitable host locations. As this is the case the response of the different varieties (genotypes or G) to the treatments in the different regions (environment or E) is a factor, referred to as the G x E interaction.

The trials results provide no evidence to support that hypothesis that it would be beneficial for application of N to take place at an earlier stage of the crop, i.e. at leaf emergence when that falls within the NVZ closed period. From many perspectives this should be viewed as positive outcome of the trial - the NVZ closed period exists to protect the environment in certain areas, preventing leaching of nitrates into surface water. If there is no benefit in applying during this period, then there is no value in risking N leaching into the water system. This also means that N applied during this period where NVZ restrictions do not apply, is likely to be less effective than if it is applied later in the growth stage of the plant.

A rate response was observed in the results obtained for bulb weight, but not for stem length or for number of stems produced. The observations from the Lincolnshire trial suggest that the influence from the year (environment), is a greater influence for stem length than N application, but in the Cornwall trial little response to year or treatment was observed. This could either be a result of more similar environmental conditions over the 3-year period, or that the variety (Karenza) is not greatly influenced in the respect.

The weight of bulbs harvested at the end of the trial was higher with the application of N at a rate of 80 kg/ha; the percentage increase varied with the trial site, in the Cornwall trial this was 9.6% higher than with the untreated plots and in the Lincolnshire trial this was 21% greater. Based on the data obtained it is not possible to say if the increase in yield is influenced by the variety response to the treatment as well as the trial location, but this seems possible. However, we must also consider the soil type, and aspect of the land in relation to the likelihood of NO_3 being leached from the soil at different rates at the different locations. The soil type at the Lincolnshire site is a clayey loam with level aspect as opposed to free draining loam on a slope at the Cornwall site.

Results from this study indicate that rates of N at 50 kg/ha or lower do not have any positive impact.

Like the data obtained for stem length, the number of stems does not appear to have been positively influenced by the application of N in this study. At both trial sites the number of stems increased over the 3 years of the work, at this point the practice of both host farmers is to end flower production and harvest the bulbs. Due to this and the duration of the project it has not been possible to investigate the impact of increased bulb weight from application of N at the 80 kg/ha rate, on the longer term productive of the bulbs for flower production. As the scoping study highlighted, although ending production 3 years after planting is the practice on the host farms, the declining price for bulbs has resulted in some growers continuing cut flower production for up to 7 years. Only further work would indicate if N application at this rate would have longer term benefit on stem production due to the greater bulb weight.

In investigating the incidence of FON in relation to N application the study has generated little data relating to expression of the disease, so has not established the link between N fertility and FON infection which has been previously noted in project BOF 31 (Linfield and Hanks.,1994).

It is possible that the rates applied were sufficiently low to not given rise to the problem, or that the varieties had sufficient resistance to FON to make the infection rates too low. Variety resistance to FON is well studied (Bowes, S.A *et al* 1992) but the trial design had taken this into consideration, so it is not believed to be a factor. It could be that the experimental design did not take into consideration that bulbs may have rotted to the point where there is no observable trace after 3 years of the planting. As only the weight rate of planting is known and not the exact number of bulbs per m, we cannot say exact numbers lost. However, this is also possibly irrelevant as the bulbs will also have naturally multiplied vegetatively during this time, if conditions were favourable, which will have changed the observable and potential number that could have developed symptoms of FON infection. To assess the impact of N more accurately on the rate of infection, a larger scale trial would need to be designed which would allow more regular lifting of bulbs to assess for infection without being detrimental to the overall trial.

Conclusions

- N application at a rate of 80 kg/ha improved harvested bulb weight but had no impact on stem length or yield of flowers, when applied as a top dressing after leaf emergence in a 3-year production cycle (2 years of flower harvesting).
- N application at rates of 50 kg/ha or lower had no impact on harvested bulb weight, stem length, or yield of flowers, when applied as a top dressing after leaf emergence in a 3-year production cycle (2 years of flower harvesting).
- No evidence to suggest application of N at leaf emergence during the NVZ closed period has any advantage to the crop over later application, in terms of yield or stem length.
- No evidence to suggest application of N at rates of up to and including 80 kg/ha, increased the rate of FON infection.

Knowledge and Technology Transfer

Welsh Flower Network (Lantra) - Soil Health and how to unlock nutrients for flowers online event

Glossary

Genotype × Environment interaction is where expression of certain physical attributes of a plant such as size and yield are different depending on the response of genetic makeup to different environmental factors.

Nitrate Vulnerable Zones (NVZs) - The European Commission (EC) nitrates directive requires areas of land that drain into waters polluted by nitrates to be designated as Nitrate Vulnerable Zones (NVZs). Farmers with land in NVZs must follow mandatory rules to tackle nitrate loss from agriculture.

References

Bowes, S.A., Edmondson, R.N., Linfield, C.A. et al. Screening immature bulbs of daffodil (Narcissus L.) crosses for resistance to basal rot disease caused by Fusarium oxysporum f. sp. narcissi . Euphytica 63, 199–206 (1992)

Hanks, G. (2013). The Narcissus Manual. AHDB Horticulture Growers Guide.

Lillywhite, R. (2016). The application of precision agronomy to UK production of Narcissus. AHDB Research Project CP 103

Linfield, C.A., Hanks, G (1994) Control of *Fusarium oxysporum* f.sp. *narcissi*, the cause of narcissus basal rot, with thiabendazole and other fungicides. HDC project BOF 31

Appendices

Appendix 13. Soil nutrient analysis

Table 1. Results from samples at Lincolnshire trial site, samples dated 19/02/2020

ANALYTICAL REPORT

Report Number	88979-20	R619	SUE CAHILL / NIAB / HUNTINGDON ROAD / CAMBRIDGE / CB3 0LE
Date Received	21-FEB-2020		Client NARCISSUS
Date Reported	27-FEB-2020		
Project	SOIL MINERAL NITROGEN		
Reference	NARCISSUS		
Order Number			

Laboratory Reference		MINN137622	MINN137623	MINN137624	MINN137625	MINN137626	MINN137627	MINN137628	MINN137629	MINN137630
Sample Reference		PLOT 1 30	PLOT 5 30	PLOT 9 30	PLOT 10 30	PLOT 17 30	PLOT 21 30	PLOT 25 30	PLOT 30 30	PLOT 32 30
Determinand	Unit	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
pH water [1:2.5]		8.4	8.2	7.9	8.1	8.2	8.3	7.9	8.2	8.3
Available Phosphorus (Index)	mg/l	48.4 (4)	32.4 (3)	22.0 (2)	20.2 (2)	17.6 (2)	19.2 (2)	17.2 (2)	20.0 (2)	17.8 (2)
Available Potassium (Index)	mg/l	234 (2+)	260 (3)	201 (2+)	170 (2-)	174 (2-)	218 (2+)	164 (2-)	148 (2-)	141 (2-)
Available Magnesium (Index)	mg/l	88.0 (2)	104 (3)	98.2 (2)	93.5 (2)	99.1 (2)	112 (3)	99.8 (2)	90.3 (2)	96.4 (2)
Nitrate Nitrogen (Fresh)	mg/kg	0.80	1.53	0.96	0.56	0.73	0.96	0.51	0.64	0.53
Ammonium Nitrogen (Fresh)	mg/kg	0.80	0.67	0.54	0.50	0.63	0.34	0.57	1.20	0.77
Dry Matter (Fresh)	%	77.9	80.4	80.3	79.9	80.0	80.0	79.7	79.2	79.9
Available Copper EDTA	mg/l	12.8	16.2	16.8	15.3	15.2	15.4	14.6	15.2	14.7
Available Zinc EDTA	mg/l	2.6	2.2	2.0	1.7	1.6	1.7	1.6	1.6	1.5
Available Sodium	mg/l	16.1	15.3	14.0	13.4	16.8	16.0	14.3	14.8	12.9
Available Calcium	mg/l	1746	1917	1725	1786	2084	2109	2013	1859	2007
Available Sulphate	mg/l	11.8	13.8	11.6	10.5	10.9	12.9	12.0	12.3	11.5
Organic Matter LOI	% w/w	2.7	3.0	3.0	2.9	2.8	2.9	3.0	2.8	2.9
Hot Water Soluble Boron	mg/l	1.9	2.0	1.8	1.8	1.7	1.8	1.9	1.7	1.7
Available Manganese	mg/l	6.3	7.3	7.1	6.7	6.4	6.7	6.9	6.6	6.8
Available Iron	mg/l	78.5	71.9	66.4	64.5	67.7	69.1	67.2	72.5	72.6

Notes

Analysis Notes	The sample submitted was of adequate size to complete all analysis requested. The results as reported relate only to the item(s) submitted for testing. The results are presented on a dry matter basis unless otherwise stipulated.
Document Control	**This test report shall not be reproduced, except in full, without the written approval of the laboratory.**

Table 2. Results of soil nutrient analysis from samples at Cornwall trial site, samples dated 17/09/2019

Lancrop Laboratories

Analysis Results (SOIL)

Customer	GREENYARD FLOWERS VARFELL FARM PENZANCE TR20 8PQ	**Distributor**	HUTCHINSONS - AMIE HORNER
Sample Ref	TRISPEN FLD 3	**Date Received**	19/09/2019 (Date Issued: 24/09/2019)
Sample No	E319110/04		
Crop	DAFFODILS		

Analysis	Result	Guideline	Interpretation	Comments
pH	6.9	6.5	Normal	Adequate level. Maintain pH to ensure optimum nutrient nutrient availability and ideal conditions for an active soil biology.
Phosphorus (ppm)	28	26	Normal	**(Index 3.1)** Adequate level.
Potassium (ppm)	326	241	Normal	**(Index 3.5)** Adequate level.
Magnesium (ppm)	117	100	Normal	**(Index 3.2)** Adequate level.
Calcium (ppm)	2244	1600	Normal	Adequate level.
Sulphur (ppm)	12	10	Normal	Adequate level.
Manganese (ppm)	88	65	Normal	Adequate level.
Copper (ppm)	11.7	2.1	Normal	Adequate level.
Boron (ppm)	1.01	2.10	Low	2 x 1 l/ha YaraVita BORTRAC 150.
Zinc (ppm)	17.8	4.1	High	Possible interference with the availability of Iron.
Molybdenum (ppm)	0.03	0.40	Very Low	Low priority on this crop. Other crops may be affected.
Iron (ppm)	770	200	Normal	Adequate level.
Sodium (ppm)	37	90	Very Low	Not a problem for this crop.
C.E.C. (meq/100g)	15.3	15.0	Normal	Cation Exchange Capacity indicates a soil with a good nutrient holding ability.
Org. Matter - DUMAS (%)	5.1	3.0	Normal	Good. Soils with medium to high levels of organic matter would generally be expected to have a good potential fertility and good structure, moisture retention and water infiltration. Ensure appropriate soil management practices are used to maintain organic matter levels.

Appendix 14. Trial observations and statistical analysis

Table 1. Lincolnshire trial data for stem length.

Year 1		Stem Length (mm), 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	324	401	343	372	334	328	331	342	353	349	325	250	337	323	365	420	285	361	335	403	345	372	367	355	390	348
2	G	363	404	349	377	396	299	349	285	335	383	312	353	205	296	300	332	298	227	525	268	365	339	388	355	350	338
3	H	420	355	315	396	375	360	385	280	330	415	345	360	342	391	365	370	365	378	343	288	394	363	386	333	396	362
4	D	303	342	403	387	395	333	400	370	325	382	373	358	334	415	285	308	367	355	414	493	339	357	381	397	356	367
5	C	256	367	345	346	305	389	375	354	345	377	365	326	308	331	347	373	339	287	300	244	349	336	302	389	390	338
6	B	398	313	346	417	384	352	340	353	331	325	340	413	403	329	409	315	375	418	351	372	348	346	416	350	372	365
7	E	420	380	324	378	375	373	376	346	340	346	392	336	335	364	299	344	362	373	405	387	423	392	355	411	325	366
8	F	374	323	345	324	276	332	349	380	392	333	340	341	370	390	329	334	337	340	346	405	427	361	330	375	334	351
9	D	352	393	369	377	315	378	303	347	374	323	364	405	414	287	390	423	395	391	269	360	274	348	273	384	332	354
10	F	347	333	386	421	342	337	378	368	410	321	373	364	346	372	342	387	349	447	357	426	456	435	379	361	404	378
11	A	310	332	390	372	385	363	379	343	354	328	312	304	376	302	296	308	376	416	298	273	343	356	372	353	354	344
12	H	359	396	344	403	379	386	360	407	380	411	380	372	405	372	386	363	382	386	432	353	376	443	382	394	362	385
13	C	369	326	350	315	340	346	365	482	507	405	392	453	368	375	395	378	362	372	295	362	379	386	342	377	350	376
14	E	470	368	472	356	373	342	402	311	436	319	225	293	372	416	438	466	392	419	325	313	368	298	378	371	352	371
15	G	330	287	355	371	357	392	297	415	397	334	373	382	299	329	310	312	387	280	433	331	324	381	365	301	372	349
16	B	367	398	464	385	389	402	355	358	394	345	332	406	365	378	344	389	344	355	334	315	394	340	330	340	312	365
17	H	370	375	346	380	315	395	340	280	310	309	345	295	334	312	328	323	303	315	322	283	285	320	384	340	281	328
18	F	296	352	468	413	345	329	311	367	327	371	376	337	364	382	321	347	333	385	306	369	314	378	365	-	-	355
19	G	370	338	400	340	400	315	395	320	420	360	353	382	420	340	390	420	390	350	382	368	385	390	395	315	400	374
20	B	295	341	356	300	296	331	366	360	336	321	320	352	354	335	378	298	342	368	354	310	394	330	359	345	344	339
21	C	360	394	359	310	325	320	395	386	308	372	400	325	330	328	322	374	315	342	372	385	382	400	344	330	345	353
22	D	327	374	336	349	336	321	321	326	415	312	292	370	332	407	361	313	345	366	297	345	337	357	298	295	376	340
23	E	364	400	329	318	364	300	366	300	394	370	330	340	305	361	378	355	358	364	360	356	338	342	338	340	348	349
24	A	370	382	400	330	370	300	360	323	360	321	375	360	340	355	372	382	370	345	344	365	362	370	395	342	368	358
25	H	245	349	315	367	372	387	336	352	342	390	331	316	338	365	298	328	331	345	401	392	382	434	342	402	423	355
26	D	353	356	324	328	334	330	362	260	356	300	322	362	338	345	311	323	305	360	290	320	330	326	355	340	328	330
27	E	420	452	370	355	410	378	290	330	305	344	378	320	324	315	355	382	356	410	283	380	346	360	366	330	315	355
28	A	398	396	383	403	365	392	340	355	352	365	341	356	328	355	345	330	358	358	346	298	334	345	342	320	362	355
29	C	335	340	378	355	310	265	305	400	335	355	358	374	350	335	340	322	320	330	360	344	312	306	364	298	300	336
30	B	263	383	318	344	315	338	347	312	315	372	366	298	385	395	360	299	338	382	371	378	276	362	292	368	355	341
31	G	390	330	320	318	380	380	340	380	330	320	356	364	370	330	311	380	373	344	346	352	375	382	374	319	358	353
32	F	328	322	352	322	295	258	282	332	362	330	333	378	334	325	314	360	348	324	320	334	350	344	389	322	386	334

Year 2		Stem Length (mm), 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	415	323	323	351	331	354	348	297	320	341	345	370	342	202	330	342										333
2	G	295	310	330	350	415	345	440	355	400	410	470	415	335													375
3	H	419	402	365	394	329	228	332	333	374	396	348	382	372	402	354	334	352	341	458	402	260	448	398	369	375	367
4	D	208	432	291	168	380	348	420	341	325	368	205															317
5	C	340	380	400	380	370	340	320	510	385	440	370	370	340	410	290	430	360	370	355	360	490	450	344	510	195	380
6	B	399	378	375	432	386	339	404	382	355	456	379	365	471	366	286	378	303	397	463	408	469	159	376	365	322	377
7	E	240	469	348	416	452	342	338	362	443	442	391	299	371													378
8	F	390	430	370	450	370	475	360	340	325	295	295	330	370	400	440	335	390	420	380	375	350	310	340	375	420	373
9	D	455	322	413	385	358	349	425	334	405	396	474	282	361	325	220	318	259	295	348	365	409	210	439	404	444	360
10	F	453	372	367	418	550	320	363	455	376	422	369	371	382	356	338	279	434	375	450	366						391
11	A	340	430	410	315	410	385	365	265	325	355	420	375	465	450	470	305	330	345	280	370	410	370	430	470	390	379
12	H	450	403	376	360	405	346	339	388	392	333	402	331	330	300	445	366	342	398	284	346	209	152	299	475	449	357
13	C	238	442	312	414	355	315	353	362	376	450	439	340	378	395	380	340	300	412	466							372
14	E	340	410	390	420	430	255	310	455	385	410	280	210	450	350	385	315	300	380	430	350	465	375	335	375	410	369
15	G	384	303	405	452	176	472	210	361	481	464	298	459	299	401	451	375	414	350	340	273	415	404	418	463	462	381
16	B	491	346	442	490	280	451	425	464	454	402	360	263	330	369	315	440										395
17	H	420	420	400	470	420	495	400	370	460	355	315	275	310	330	300	300	410	335	365	480	340	315	390	350	345	375
18	F	398	311	380	342	303	366	235	356	313	423	370	350	415	396	290	460	370	334	350	338	347	170	348	376	380	349
19	G	334	433	188	392	470	344	402	328	358	452	314	414	142													352
20	B	415	485	500	400	430	320	390	325	430	360	345	425	440	320	390	190	430	335	400	310	410	470	340	370	400	385
21	C	362	465	456	461	295	480	373	430	450	416	468	500	416	436	392	405	447	390	324	296	342	450	415	436	462	415
22	D	420	451	386	351	165	342	329	298	304	365	372	355	323	345	326	275	315	412	362	369						343
23	E	300	400	340	380	360	415	400	415	440	430	450	330	410	400	360	430	270	450	260	285	325	420	355	390	380	376
24	A	430	444	450	450	378	256	278	443	365	418	417	496	318	382	425	240	492	404	376	318	389	270	336	420	360	382
25	H	330	236	417	384	377	279	363	393	332	362	441	321	326	370	374	430	492									366
26	D	365	415	410	360	410	355	365	340	330	375	410	330	340	470	465	370	380	430	390	350	410	340	360	350	470	384
27	E	414	368	442	460	347	435	316	354	382	404	424	446	325	270	463	358	360	333	365	290	262	205	372	319	356	363
28	A	378	350	316	256	455	325	391	500	493	453	321	335														381
29	C	375	440	320	420	405	350	230	385	370	465	410	300	345	400	365	490	295	375	335	350	330	320	410	375	390	370
30	B	400	560	422	522	403	398	300	194	401	386	349	385	335	325	395	409	383	380	445	296	348	409	344	398	392	383
31	G	420	288	465	462	402	446	321	312	330	379	505	345	351	246	464	329	498	217	255	325	369	418	480			375
32	F	315	350	380	380	380	350	385	355	320	330	340	440	370	440	365	370	350	345	370	380	420	440	400	380	490	378

Year 3		Stem Length (mm), 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	160	180	140	150	200	170	150	140	180	150	160	160	150	200	160	150	50	180	180	160	160	150	180	100	150	156
2	G	120	120	80	90	140	80	160	170	100	170	160	170	130	140	170	130	160	90	130	170	150	160	160	150	160	138
3	H	140	170	170	150	160	150	100	160	150	150	160	150	140	140	160	130	100	150	170	170	200	150	140	120	170	150
4	D	140	140	160	140	140	160	140	110	130	140	140	160	60	150	140	150	150	180	140	140	150	120	130	140	170	141
5	C	120	130	80	160	140	120	120	170	150	150	140	160	140	150	130	140	120	150	140	130	130	140	100	140	160	136
6	B	160	160	150	160	160	120	160	100	150	160	120	120	160	110	160	160	150	130	90	180	200	200	190	170	150	151
7	E	120	130	140	160	150	130	150	100	110	90	150	190	190	130	180	170	160	160	140	140	130	110	180	130	140	143
8	F	140	110	140	140	120	170	130	100	150	110	110	160	140	140	150	130	150	150	110	160	130	170	160	130	150	138
9	D	160	180	110	130	110	100	150	180	80	150	150	110	130	110	120	160	120	110	150	100	150	120	160	190	180	136
10	F	160	180	170	100	140	110	160	160	140	180	120	150	120	190	180	180	170	150	120	140	130	160	130	140	140	149
11	A	140	140	90	110	140	120	160	130	140	120	90	150	150	90	150	110	170	120	160	140	160	110	140	140	140	132
12	H	160	130	50	140	140	140	110	130	130	90	120	150	160	160	160	160	130	120	160	180	190	150	140	130	160	140
13	C	140	140	120	100	140	150	120	110	120	150	130	80	150	150	170	120	180	160	140	140	190	190	150	160	160	142
14	E	120	120	140	150	110	150	110	150	70	160	130	130	140	180	160	180	160	90	160	110	130	110	120	140	160	135
15	G	110	110	140	130	120	100	140	160	160	120	110	130	150	150	140	180	110	150	150	100	140	130	150	140	110	133
16	B	140	100	150	120	140	150	130	160	110	170	140	180	200	240	150	200	200	190	180	180	160	200	200	160	160	164
17	H	60	85	110	170	140	120	120	120	160	110	110	130	90	100	130	140	80	110	110	110	90	60	130	120	130	113
18	F	230	220	240	220	250	300	220	250	230	300	270	260	250	240	290	270	220	320	230	330	320	310	230	310	200	260
19	G	210	170	290	260	190	210	240	250	260	200	180	160	140	210	150	190	210	190	160	210	150	210	200	190	220	202
20	B	100	110	270	50	70	90	120	90	130	150	140	150	140	100	120	80	150	170	220	100	130	110	180	120	90	127
21	C	240	300	290	250	230	160	160	290	210	300	320	220	250	100	100	120	130	180	130	320	140	290	210	200	180	213
22	D	130	280	150	180	170	160	210	180	210	120	170	140	170	150	210	250	130	180	120	190	110	190	190	140	170	172
23	E	130	90	120	110	100	100	110	110	100	110	90	120	120	110	80	120	110	130	250	260	80	70	140	110	100	119
24	A	290	230	240	240	220	230	280	180	260	250	220	220	210	220	160	120	130	120	150	160	190	200	130	140	260	202
25	H	200	150	170	140	140	160	200	150	200	310	160	160	140	210	260	150	110	150	140	120	160	80	250	190	180	171
26	D	150	70	120	100	120	120	150	130	90	120	120	110	150	110	90	100	110	100	120	50	80	140	150	110	100	112
27	E	160	120	120	110	140	110	100	120	130	130	100	80	110	170	170	120	120	100	160	140	170	160	80	250	110	131
28	A	270	260	250	170	200	180	120	270	290	180	140	130	240	160	210	120	80	200	130	170	180	180	210	180	200	189
29	C	110	100	120	80	290	120	110	80	90	90	110	120	130	90	100	90	110	120	120	120	90	110	80	110	80	111
30	B	120	80	120	120	120	90	120	60	120	130	90	70	80	70	150	140	160	150	170	150	110	180	100	160	150	120
31	G	220	150	140	160	120	170	170	110	140	160	140	180	150	160	180	150	170	140	150	180	110	140	170	90	140	152
32	F	70	80	120	50	160	140	110	220	120	140	130	90	120	140	120	110	80	200	110	70	100	100	110	150	60	116

```
94 "General analysis of variance"
95 BLOCK Rep
96 TREATMENTS Trt*Year
97 COVARIATE "No Covariate"
98 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
99 PSE=diff,lsd; LSDLEVEL=5] lengthnoy1
```

Analysis of variance

Variate: lengthnoy1

Source of	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	4092.6	1364.2	1.89	
Rep.*Units* stratum					
Trt	7	4391	627.3	0.87	**0.537**
Year	1	783682	783682	1087.55	**<.001**
Trt.Year	7	3739.7	534.2	0.74	**0.638**
Residual	45	32426.8	720.6		
Total	63	828332			

Message: the following units have large residuals.

Rep 3 *un 81.1 approx. s.e. 22.5

Tables of means

Variate: lengthnoy1

Grand mean 260.6

Trt	A	B	C	D	E	F	G	H
	269.4	262.9	267.4	245.6	251.7	269.3	263.5	254.8

Year	1	2	3
		371.2	149.9

Trt	Year	1	2	3
A			369	169.9
B			385	140.7
C			384.2	150.6
D			350.9	140.4
E			371.3	132.1
F			372.7	165.8
G			370.6	156.3
H			366.1	143.5

Least significant differences of means (5% level)

Table	Trt	Year	Trt Year
rep.	8	32	4
d.f.	45	45	45
l.s.d.	**27.03**	**13.52**	**38.23**

Table 2. Lincolnshire trial data for number of stems

Year 1		Number of Flower Stems per Bulb, 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
26	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
28	A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31	G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Year 2		Number of Flower Stems per Bulb, 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1										1.063
2	G	1	1	3	1	1	2	2	1	2	1	3	2	3													1.769
3	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1.040
4	D	1	2	1	1	1	1	2	1	1	2	1															1.273
5	C	1	2	2	2	2	1	1	1	2	3	3	1	1	1	1	2	1	2	2	2	1	2	1	1	1	1.560
6	B	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.040
7	E	1	1	1	1	1	1	1	1	1	1	1	1	1													1.000
8	F	1	1	2	2	1	1	1	1	4	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	2	1.320
9	D	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1.160
10	F	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1						1.050
11	A	3	1	1	1	1	3	1	1	1	1	1	1	1	1	2	1	1	1	2	4	1	1	2	3	3	1.560
12	H	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.040
13	C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1							1.053
14	E	2	2	3	2	2	1	1	1	1	1	1	1	1	2	1	2	1	1	2	1	1	1	1	2	2	1.440
15	G	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1.120
16	B	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1										1.063
17	H	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1.160
18	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.000
19	G	1	1	1	1	1	1	1	1	1	1	1	1	1													1.000
20	B	2	1	2	1	1	1	1	1	1	1	2	2	1	1	2	1	1	2	1	1	2	1	1	1	1	1.280
21	C	1	1	1	1	1	1	1	1	1	1	1	1	3	1	2	2	2	2	1	1	2	1	2	2	1	1.360
22	D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1.000
23	E	1	2	1	1	1	1	1	3	1	1	2	1	1	1	1	1	2	1	1	1	1	2	1	2	1	1.280
24	A	2	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	2	2	1	4	1	1	1	1	1.320
25	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2									1.118
26	D	1	1	2	3	1	1	1	1	1	1	2	1	1	2	1	1	1	1	2	1	1	1	1	1	1	1.240
27	E	1	2	1	1	1	2	1	1	1	2	1	1	1	1	2	1	2	2	4	1	1	1	1	1	1	1.360
28	A	1	1	1	1	1	1	1	1	1	1	1	1														1.000
29	C	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1.080
30	B	1	1	1	1	1	1	1	1	2	1	2	2	1	1	2	1	3	1	1	1	1	1	3	1	3	1.400
31	G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1			1.043
32	F	1	1	1	1	1	1	1	1	2	1	1	2	1	2	2	1	1	1	1	1	1	2	1	1	1	1.200

Year 3		Number of Flower Stems per Bulb, 25 Bulbs per Plot																									
Plot	Trt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Av
1	A	2	2	1	1	1	1	2	1	1	2	1	1	2	1	2	1	1	1	1	1	1	2	1	1	1	1.2800
2	G	2	1	1	2	1	2	3	2	1	3	1	1	2	2	2	1	3	1	2	1	1	1	2	1	1	1.6000
3	H	2	1	2	1	2	2	1	1	1	1	1	1	3	1	1	2	1	2	1	1	2	2	2	1	1	1.4400
4	D	1	1	1	1	2	2	1	2	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1.2000
5	C	1	2	1	2	1	1	1	1	1	1	1	1	2	1	1	1	2	2	1	1	1	1	2	1	2	1.2800
6	B	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	1	1	2	1	1	1	1	1	2	2	1.2800
7	E	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	2	1	1	1.2000
8	F	1	1	1	2	2	3	1	2	2	1	2	3	1	1	1	1	3	2	1	3	1	1	1	1	1	1.5600
9	D	1	2	1	1	2	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	2	1	1	1.2800
10	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	1	1.1200
11	A	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1	2	1	1.2000
12	H	1	1	1	2	1	1	3	1	1	3	1	2	1	1	2	1	1	3	1	2	1	2	1	1	2	1.4800
13	C	1	1	1	1	1	1	1	1	1	1	2	1	3	2	2	1	1	1	1	2	1	1	1	2	1	1.2800
14	E	1	1	2	2	2	2	1	1	1	2	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1.2800
15	G	1	2	2	1	1	1	1	2	1	2	2	1	1	1	1	2	1	3	1	1	1	1	2	1	1	1.3600
16	B	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	2	1	1.2000
17	H	1	3	1	2	1	1	2	5	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1.3600
18	F	2	1	2	4	1	2	2	3	1	2	2	2	1	3	2	2	1	2	1	1	2	2	1	2	1	1.8000
19	G	3	2	3	1	1	2	1	2	3	1	1	1	1	1	1	1	1	3	2	3	1	1	1	1	1	1.5600
20	B	1	2	1	1	1	1	1	2	1	2	3	2	1	1	1	1	1	1	1	2	3	2	1	1	1	1.4000
21	C	1	2	1	3	1	1	2	1	1	2	1	2	1	2	1	2	1	1	2	1	1	3	1	1	1	1.4400
22	D	1	1	1	2	1	1	1	2	1	1	1	1	2	1	1	1	1	2	2	1	1	1	2	2	1	1.2800
23	E	1	1	3	2	1	2	2	3	2	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1.4000
24	A	2	1	2	1	2	2	1	1	1	2	1	1	1	2	1	1	2	1	1	1	1	2	1	2	3	1.4400
25	H	2	3	1	1	1	1	2	1	3	1	2	1	1	1	1	1	1	1	1	3	2	1	2	1	2	1.4800
26	D	1	1	1	2	1	2	3	1	1	1	1	1	1	1	1	1	1	2	2	1	1	3	1	1	1	1.3200
27	E	1	2	2	1	2	2	1	2	2	1	1	1	1	2	2	1	1	1	1	1	2	1	1	1	1	1.3600
28	A	2	1	1	1	1	2	1	2	1	1	1	1	1	3	1	1	1	2	1	1	2	1	1	1	1	1.2800
29	C	1	2	2	1	2	3	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1.2800
30	B	2	1	1	1	1	1	2	1	1	1	1	1	3	2	2	1	1	1	1	1	2	1	1	1	1	1.2800
31	G	1	1	2	2	1	2	2	1	1	2	1	2	1	1	2	1	1	1	1	2	1	2	1	1	2	1.4000
32	F	1	1	2	1	4	1	1	1	1	1	1	2	4	2	1	3	1	1	1	1	2	1	3	2	1	1.6000


```
100 "General analysis of variance"
101 BLOCK Rep
102 TREATMENTS Trt*Year
103 COVARIATE "No Covariate"
104 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
105  PSE=diff,lsd; LSDLEVEL=5] stems_per_bulb_noy1
```

Analysis of variance

Variate: stems_per_bulb_noy1

Source of	d.f.	s.s.	m.s.	v.r.	**F pr.**
Rep stratu	3	0.07277	0.02426	0.77	
Rep.*Units* stratum					
Trt	7	0.11305	0.01615	0.52	**0.818**
Year	1	0.44377	0.44377	14.17	**<.001**
Trt.Year	7	0.26541	0.03792	1.21	**0.317**
Residual	45	1.40934	0.03132		
Total	63	2.30434			

Message: the following units have large residuals.

Rep 1 *uni	0.513	approx. s.e. 0.148
Rep 2 *un	0.377	approx. s.e. 0.148
Rep 2 *un	-0.347	approx. s.e. 0.148

Tables of means

Variate: stems_per_bulb_noy1

Grand mean 1.283

Trt	A	B	C	D	E	F	G	H
	1.268	1.243	1.292	1.219	1.29	1.331	1.357	1.265

Year	1	2	3
		1.20	1.366

Trt	Year	1	2	3
A			1.236	1.3
B			1.196	1.29
C			1.263	1.32
D			1.168	1.27
E			1.27	1.31
F			1.143	1.52
G			1.233	1.48
H			1.089	1.44

Least significant differences of means (5% level)

Table	Trt	Year	Trt Year
rep.	8	32	4
d.f.	45	45	45
l.s.d.	**0.1782**	**0.0891**	**0.252**

Table 3. Lincolnshire trial data for number of bulbs, fresh weight of bulbs and incidence of basal rot.

Final Assessment 15/06/22								
		Basal Rot Score (1 absent, 5 very severe) 1m section (bulbs per plot)						
Plot	Trt	1	2	3	4	5	Total Bulbs/Plot	Fresh weight of Bulbs (g)
1	A	96	0	1	1	1	99	346
2	G	52	1	0	1	0	54	218
3	H	86	0	0	1	0	87	297
4	D	130	0	0	0	0	130	443
5	C	11	0	2	0	0	13	373
6	B	114	0	1	0	0	115	354
7	E	159	0	0	0	0	159	458
8	F	92	1	0	1	0	94	372
9	D	93	0	0	0	0	93	321
10	F	149	0	0	0	0	149	438
11	A	74	1	0	0	0	75	336
12	H	105	0	0	0	0	105	416
13	C	151	1	0	0	0	152	574
14	E	77	4	0	0	0	81	343
15	G	117	0	0	0	0	117	389
16	B	146	2	0	0	0	148	449
17	H	90	2	0	0	0	92	350
18	F	132	0	0	0	0	132	545
19	G	147	2	0	0	0	149	451
20	B	93	0	1	0	0	94	339
21	C	130	1	0	0	0	131	419
22	D	109	6	0	0	0	115	355
23	E	87	0	0	0	0	87	313
24	A	111	0	0	0	0	111	344
25	H	120	0	0	0	0	120	330
26	D	91	0	0	0	0	91	345
27	E	116	0	0	0	0	116	455
28	A	89	0	1	0	0	90	255
29	C	89	2	0	0	0	91	315
30	B	112	0	0	0	0	112	437
31	G	111	0	0	0	0	111	312
32	F	91	0	0	0	0	91	325

```
80 "General analysis of variance"
81 BLOCK Rep
82 TREATMENTS Trt
83 COVARIATE "No Covariate"
84 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
85  PSE=diff,lsd; LSDLEVEL=5] Total_Bulbs_Plot
```

Analysis of variance

Variate: Total_Bulbs_Plot

Source of	d.f.	(m.v.)	s.s.	m.s.	v.r.	**F pr.**
Rep stratu	3		7148	2383	2.11	
Rep.*Units* stratum						
Trt	7		6236	891	0.79	**0.605**
Residual	21	-64	23725	1130		
Total	31	-64	28220			

Message: the following units have large residuals.

Rep 1 *uni	-41.3	s.e. 15.7
Rep 1 *uni	35.2	s.e. 15.7
Rep 1 *uni	-71.3	s.e. 15.7
Rep 1 *uni	60.7	s.e. 15.7
Rep 2 *un	46.6	s.e. 15.7
Rep 2 *un	-38.3	s.e. 15.7
Rep 3 *un	33.8	s.e. 15.7

Tables of means

Variate: Total_Bulbs_Plot

Grand mean 106.4

Trt	A	B	C	D	E	F	G	H
	93.8	117.2	96.8	107.2	110.7	116.5	107.7	101

Least significant differences of means (5% level)

Table	Trt
rep.	12
d.f.	21
l.s.d.	**28.54**

```
86 "General analysis of variance"
87 BLOCK Rep
88 TREATMENTS Trt
89 COVARIATE "No Covariate"
90 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
91 PSE=diff,lsd; LSDLEVEL=5] Fresh_weight_of_Bulbs_g
```

Analysis of variance

Variate: Fresh_weight_of_Bulbs_g

Source of	d.f.	(m.v.)	s.s.	m.s.	v.r.	**F pr.**
Rep stratu	3		57685	19228	3.27	
Rep.*Units* stratum						
Trt	7		114769	16396	2.79	**0.032**
Residual	21	-64	123542	5883		
Total	31	-64	181292			

Message: the following units have large residuals.

Rep 1 *uni	-106.7	s.e. 35.9
Rep 1 *uni	94.8	s.e. 35.9
Rep 1 *uni	83.7	s.e. 35.9
Rep 2 *un	-77.7	s.e. 35.9
Rep 2 *un	121.2	s.e. 35.9
Rep 2 *un	-81.9	s.e. 35.9
Rep 3 *un	111.2	s.e. 35.9
Rep 3 *un	94.5	s.e. 35.9
Rep 3 *un	-93.1	s.e. 35.9
Rep 4 *un	91.5	s.e. 35.9
Rep 4 *un	-76.4	s.e. 35.9

Tables of means

Variate: Fresh_weight_of_Bulbs_g

Grand mean 375.5

Trt	A	B	C	D	E	F	G	H
	320.4	394.7	420.1	366	392.2	419.9	342.6	348.3

Least significant differences of means (5% level)

Table	Trt
rep.	12
d.f.	21
l.s.d.	**65.12**

Table 4. Cornwall trial data for stem length

		Stem Height (cm)		
Plot	Treatment	Year 1	Year 2	Year 3
101	A	25	23	24
102	F	24	24	25
103	B	26	27	30
104	E	23	24	25
105	H	26	24	24
106	D	28	23	26
107	C	26	24	28
108	G	24	25	28
201	D	24	25	26
202	H	31	25	23
203	E	30	26	27
204	C	27	28	26
205	F	29	23	26
206	B	27	23	25
207	G	30	26	22
208	A	26	27	30
301	H	27	25	21
302	D	28	25	24
303	A	30	25	23
304	B	24	27	25
305	F	28	27	26
306	G	25	27	24
307	E	28	25	24
308	C	25	26	27
401	A	29	26	21
402	F	25	25	24
403	E	30	28	22
404	D	27	27	23
405	G	27	26	24
406	C	26	26	24
407	H	29	27	28
408	B	26	30	20

```
70 "General analysis of variance"
71 BLOCK REP
72 TREATMENTS Treatment_1*YEAR
73 COVARIATE "No Covariate"
74 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
75 PSE=diff,lsd; LSDLEVEL=5] Height
```

Analysis of variance

Variate: Height

Source of	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratu	3	2.062	0.688	0.13	
REP.*Units* stratum					
Treatmen	7	15.188	2.17	0.4	0.896
YEAR	1	9	9	1.67	0.203
Treatmen	7	9.75	1.393	0.26	0.967
Residual	45	242.938	5.399		
Total	63	278.938			

Message: the following units have large residuals.

REP 1 *un	4.97	approx. s.e. 1.95
REP 2 *ur	5.22	approx. s.e. 1.95
REP 4 *ur	-4.84	approx. s.e. 1.95

Tables of means

Variate: Height

Grand mean 25.22

Treatmen	A	B	C	D	E	F	G	H
	24.88	25.88	26.12	24.88	25.12	25	25.25	24.62

YEAR	1	2	3
		25.59	24.84

Treatmen	YEAR 1	2	3
A		25.25	24.5
B		26.75	25
C		26	26.25
D		25	24.75
E		25.75	24.5
F		24.75	25.25
G		26	24.5
H		25.25	24

Least significant differences of means (5% level)

Table	Treatmen	YEAR	Treatment_1 YEAR
rep.	8	32	4
d.f.	45	45	45
l.s.d.	**2.34**	**1.17**	**3.309**

Table 5. Cornwall trial data for population

		Population - Plants/ row meter		
Plot	Treatment	Year 1	Year 2	Year 3
101	A	68	58	66
102	F	67	55	83
103	B	47	60	70
104	E	49	53	67
105	H	53	58	74
106	D	54	72	74
107	C	53	49	83
108	G	46	50	87
201	D	54	64	75
202	H	60	60	80
203	E	51	60	87
204	C	63	59	70
205	F	44	56	70
206	B	54	58	78
207	G	53	54	76
208	A	59	48	80
301	H	65	58	75
302	D	44	55	86
303	A	55	50	70
304	B	49	48	85
305	F	40	60	74
306	G	58	58	82
307	E	43	55	87
308	C	57	60	79
401	A	59	60	72
402	F	60	70	76
403	E	47	61	70
404	D	52	48	75
405	G	45	55	58
406	C	52	57	64
407	H	57	63	88
408	B	51	53	61

```
76 "General analysis of variance"
77 BLOCK REP
78 TREATMENTS Treatment_1*YEAR
79 COVARIATE "No Covariate"
80 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
81 PSE=diff,lsd; LSDLEVEL=5] pop
```

Analysis of variance

Variate: pop

Source of	d.f.	s.s.	m.s.	v.r.	**F pr.**
REP stratu	3	96.17	32.06	0.57	
REP.*Units* stratum					
Treatmen	7	309.11	44.16	0.79	**0.6**
YEAR	1	5568.89	5568.89	99.6	**<.001**
Treatmen	7	48.48	6.93	0.12	**0.996**
Residual	45	2516.08	55.91		
Total	63	8538.73			

Message: the following units have large residuals.

REP 4 *ur -15.83 approx. s.e. 6.27

Tables of means

Variate: pop

Grand mean 66.36

Treatmen	A	B	C	D	E	F	G	H
	63	64.12	65.12	68.62	67.5	68	65	69.5

YEAR	1	2	3
		57.03	75.69

Treatmen	YEAR 1	2	3
A		54	72
B		54.75	73.5
C		56.25	74
D		59.75	77.5
E		57.25	77.75
F		60.25	75.75
G		54.25	75.75
H		59.75	79.25

Least significant differences of means (5% level)

Table	Treatmen	YEAR	Treatment_1 YEAR
rep.	8	32	4
d.f.	45	45	45
l.s.d.	7.53	3.765	10.649

Table 6. Cornwall trial data for number of bulbs, fresh weight of bulbs and incidence of basal rot.

Final Assessment 26/05/2022						
Plot	Treatment	Basal Rot%	Number of Diseased Bulbs	Fresh Wt	Dry Wt	DM%
101	A	0	1	722	237.8	32.9
102	F	0	0	787	254.2	32.3
103	B	0	0	678.2	218.5	32.2
104	E	0	0	786.7	264.5	33.6
105	H	0	0	759.9	260.1	34.2
106	D	0	1	699.2	239.5	34.3
107	C	0	0	670.6	215.4	32.1
108	G	0	1	710.5	239.3	33.7
201	D	0	0	694.8	237.8	34.2
202	H	0	0	665.4	234.2	35.2
203	E	0	0	790.7	204.3	25.8
204	C	0	0	708	231.6	32.7
205	F	0	0	916.4	319	34.8
206	B	0	0	707.5	243.2	34.4
207	G	0	0	753.6	258.3	34.3
208	A	0	0	778.1	259.9	33.4
301	H	0	0	757.9	277.6	36.6
302	D	0	0	779.9	261	33.5
303	A	0	0	633.4	204.7	32.3
304	B	0	0	653	232	35.5
305	F	10	1	860.2	286.7	33.3
306	G	0	0	714.5	235	32.9
307	E	0	0	788.8	258	32.7
308	C	0	0	658.8	213.5	32.4
401	A	0	0	706	227.9	32.3
402	F	0	0	611.3	200.8	32.8
403	E	0	0	766.6	250.3	32.7
404	D	0	0	737.8	250.3	33.9
405	G	0	0	732.6	251.6	34.3
406	C	0	0	590.5	208.2	35.3
407	H	0	0	701.3	234.6	33.5
408	B	0	0	573.8	198.2	34.5

```
91 "General analysis of variance"
 92 BLOCK REP
 93 TREATMENTS Treatment
 94 COVARIATE "No Covariate"
 95 ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7; PCONTRASTS=7; FPROB=yes;\
 96  PSE=lsd; LSDLEVEL=5] fresh_wt
```

Analysis of variance

Variate: fresh_wt

Source of variatic	d.f.	(m.v.)	s.s.	m.s.	v.r.	**F pr.**
REP stratum	3		71080	23693	7.17	
REP.*Units* stratum						
Treatment	7		216311	30902	9.35	**<.001**
Residual	21	-64	69401	3305		
Total	31	-64	165474			

Message: the following units have large residuals.

REP 2 *units* 1	-63.2	s.e. 26.9
REP 2 *units* 2	-85.8	s.e. 26.9
REP 2 *units* 5	92.7	s.e. 26.9
REP 3 *units* 3	-85.6	s.e. 26.9
REP 3 *units* 5	57.5	s.e. 26.9
REP 4 *units* 2	-138.2	s.e. 26.9
REP 4 *units* 4	54.1	s.e. 26.9

Tables of means

Variate: fresh_wt

Grand mean 721.7

Treatmen	A	B	C	D	E	F	G	H
	709.9	653.2	657.1	727.9	783.1	793.6	727.8	721.1

includes a much lower rep 4

Least significant differences of means (5% level)

Table	Treatment
rep.	12
d.f.	21
l.s.d.	48.81

Introduction – Section 4. The effects of NO_3 versus NH_4 based fertilisers / plant nutrients on plant growth and quality

Plants are known to affect substrate pH due to differences in uptake of cation and anion nutrients (Haynes, 1990; Lea-Cox *et al.*, 1996; Marschner, 1995), and work on protected ornamental species has examined the relationship between NO_3/NH_4 application ratio, anion/cation uptake ratio, rhizosphere pH and micronutrient solubility (Dikerson and Fisher, 2017). As has the fact that the way plants alter the rhizosphere pH varies at the cultivar level in some crops (Froehlich and Fehr, 1981; Saxena and Sheldrake, 1980).

Assimilation of NO_3 into NH_4 has to take place in plants and the process has a high energy requirement, so it is considered most energy efficient to supply N to plants in a mix of both NO_3 and NH_4. The aim of the work carried out in the study was to demonstrate the way pH changes in response to N when it is supplied as either NH_4 or NO_3, and how the impact is different in different plant species and how that might relate to the availability of other macro and micronutrients.

Due to the amount of literature available on this topic, the conclusion from the scoping study was that it was unnecessary to carry out in depth investigations and unrealistic to develop detailed recommendations for N-form application, however the production of best practice advice backed by demonstration trials would be of benefit.

The trial design took into consideration species which have differing imbalances in anion and cation uptake during growth and can subsequently suffer with different deficiencies due to changes in growing media pH, the current availability of commercial fertiliser formulations was also a consideration.

Materials and methods

The investigation was untaken between May and August of 2020, in a glasshouse at NIAB's Cambridge trial site. The glasshouse was set to maintain a minimum temperature of 10 ^{o}C, no supplementary lighting was provided, and no shade screens were utilised. The trial was carried out on a tabletop bench fitted with Stal & Plast liners.

Crops with different nutritional requirements were selected to investigate the difference in response. Cyclamen has a lower nutrient requirement, pansy has a higher nutrient requirement and causes pH to increase over time, and geranium which drives pH down over time.

The test plants were as follows:

- Pansy 'Matrix® Blue Blotch' – grown at the trial site from commercial supplied seed by Ball Colegrave

- Geranium zonal ‘Designer Scarlet Bright’ – obtained as plug plants from Ball Colegrave during week 20.
- Cyclamen F1 ‘Metis® White’ – obtained as plug plants from Ball Colegrave during week 20.

Figure 29. Overview of trial 3 set up, dated 12/08/2020.

Plants were transplanted into Soparco Duo 13 cm 5 deg (1 l) pots using a standard peat based growing media mix, the specification of which can be found in Table 17.

Table 17. Growing media specification.

Brand	ICL M2
pH range	5.3-6.0
Particle size	0-10 mm
Conductivity	228-414 µs
Nutrient added	192N 98P 319K

Irrigation to the trial was applied manually overhead using a lance. The water supply used was main supply for the area (hard water). Plants were irrigated according to need, with excess irrigation water freely draining to avoid cross contamination between treatments.

Three feed treatments were applied to the trial each with a different ratio of NH_4 and NO_3, as shown in Table 18. All treatments provided 100 ppm N (NH_4/NO_3), 45 ppm P,125 ppm K, 8 ppm Mg and trace elements.

Table 18. Treatment list – ratio of N components used to achieve 100 ppm of N in feed.

Treatment no.	NH_4	NO_3
1	0	100
2	20	80
3	30	70

The details of the feed components can be found in Tables 1 to 3 in Appendix 15 of the report.

When fertiliser straights with sulphate e.g., magnesium sulphate (MgS) are used to create the stock solutions, the potential for an increase of the media pH can be expected. To achieve the required Mg levels in all three stock feeds both MgS and magnesium nitrate (MgN) were used.

The three stock feeds were made up on 03/06/2020 and diluted at a rate of 5 ml to 1 l water (0.5% or 1:200).

Feeding started one week after potting and then on a weekly basis. At each feeding event 10 ml of the diluted solutions were applied manually by syringe to individual pots in the relevant treatments.

The trial consisted of 66 plants per species, 22 per feed treatment. They were arranged in replicated blocks to assist with application of feed and with sampling of growing media.

Observations were made throughout the trial on the incidence of deficiency symptoms, and those observed were noted and photographed.

Assessments were made on two occasions during the trial, this consisted of plant height or width (depending on species) measure in mm, a count of the number of leaves (cyclamen only), a count of the number of flowers and the fresh weight of the above ground growth in g.

Weekly observations on growing media EC and pH (SME) were made using EXTECH ExStik II meter. To maintain consistency, the SME sample was taken on the day that the feed was applied, but prior to its application.

A sample of growing media and plant tissue from each treatment was sent for laboratory analysis at the mid-point of the trial based on 10 randomly selected plants, final samples were taken from the remaining 12 plants.

Results

The trends resulting from the use of different N form ratios in this trial were not as clear as anticipated. Three crops with different nutritional requirements were selected to illustrate the way different species react, however the response was not as expected.

Weekly observations of growing media pH for all species show an initial decline in value, followed by a general increasing trend in the final six weeks of the trial. The highest values for pH were observed in pansy, followed by geranium and the lowest was in cyclamen, with no overlap in values for the three different species. Within each species there is no consistent trend linking the pH value to the N-form ratio, so final pH does not appear to be lower with increasing or decreasing amounts of NH_4 in the feed.

Table 19. Results of observation on growing media pH over duration of the trial for all treatments.

	Crop	Cyclamen			Geranium			Pansy		
	N form ratio NH_4:NO_3	0/100	20/80	30/70	0/100	20/80	30/70	0/100	20/80	30/70
Date	10/06/2020	6.14	6.16	6.05	6.43	6.43	6.29	6.25	6.28	6.25
	17/06/2020	6.15	6.11	6.04	6.18	6.17	6.17	6.12	6.14	6.17
	24/06/2020*	6.01	5.91	5.02	6.03	6.01	6.03	5.57	5.71	5.93
	01/07/2020	5.23	5.14	5.15	5.23	5.24	5.22	5.52	5.42	5.33
	08/07/2020	5.75	5.77	5.78	5.78	5.77	5.78	5.77	5.79	5.78
	15/07/2020	5.78	5.75	5.76	5.75	5.76	5.74	5.78	5.76	5.75
	23/07/2020	6.33	6.36	6.33	6.81	6.87	6.72	6.83	6.87	6.83
	30/07/2020	6.97	6.99	6.98	6.86	6.74	6.85	6.52	6.52	6.5
	05/08/2020	No observation in this week								
	13/08/2020*	6.31	6.36	6.13	7.12	6.86	7.34	7.48	7.37	7.55

*outdoor daytime temperature in excess of 30 ^{0}C during these weeks

All observations of growing media pH and EC can be seen in Tables 1, 2, and 3 of Appendix 16 of the report.

The results of the leaf tissue analysis at the mid-point and the end of the trial show a greater difference between species in SAP pH than observed in the growing media analysis. As expected, geranium has a low pH value, in this case below 4. For pansy it was in the range of 5.4-6.0 and cyclamen 5.1-5.2.

Table 20. Summary of results for all treatments for plant fresh weight, growing media and leaf tissue analysis - samples taken 17/07/2020 for mid-point, 18/08/2020 for final observations.

Species		**Cyclamen**			**Geranium**			**Pansy**		
Treatment		**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
N form ratio NH4:NO3		0/100	20/80	30/70	0/100	20/80	30/70	0/100	20/80	30/70
Plant assessment (average)										
	plant height/width (mm)	130.4	129.2	128.9	184.5	209.7	192.3	315.8	283.8	299.6
	Leaf number	11.1	13.5	16.1	-	-	-	-	-	-
	flower number	7.2	4.8	4.7	4.3	4.9	5.1	5.7	3.4	4.5
	fresh weight (g)	30.0	25.8	26.2	54.3	57.8	51.8	105.3	95.3	92.6
Plant Tissue analysis (mg/l)										
midpoint	pH	5.3	5.4	5.3	3.8	3.8	3.8	6.3	6.3	6.1
	NH4	49.3	59.3	49.7	140.0	136.1	153.9	43.7	29.1	22.7
	NO3	349.0	445.5	327.8	28.0	31.1	35.0	159.6	68.1	95.1
end point	pH	5.2	5.1	5.2	3.7	3.6	3.7	5.7	6.0	5.4
	NH4	27.2	29.1	31.0	38.5	42.2	36.0	10.3	14.9	14.0
	NO3	58.7	62.1	79.4	0.1	0.4	2.6	0.3	0.7	0.4
Growing media analysis (mg/l)										
midpoint	pH	5.9	5.7	5.6	5.8	5.8	5.9	6.1	6.2	6.1
	NH4	1.0	4.1	<0.6	0.8	0.9	2.0	<0.6	1.4	0.8
	NO3	137.5	153.0	193.3	87.2	61.8	54.0	19.1	21.1	29.7
	total sol N	138.5	157.2	193.3	88.0	62.7	56.0	19.6	22.5	30.5
end point	pH	6.1	6.1	5.9	6.3	6.4	6.5	6.4	6.4	6.6
	NH4	1.8	6.1	1.8	1.1	1.4	1.3	1.7	1.4	2.4
	NO3	24.6	50.3	46.5	<0.6	0.9	<0.6	2.7	2.0	3.7
	total sol N	26.4	56.3	48.3	1.1	2.3	1.5	4.4	3.4	6.1

The full results from the growing media and leaf tissue analysis are contained in Tables 4 and 5, Appendix 16 of the report.

In all treatments the main (or only) form of N was NO_3, however in Figure 30, very different ratios for the forms of N in the plant were seen. We would expect to find NH_4 in the leaf tissue of all treatments even where N is only supplied as NO_3 in the liquid feed (NH_4 is present in the base feed) as reduction of NO_3 to NH_4 is an essential process.

At the mid-point of the trial, pansy, and cyclamen both had more NO_3 than NH_4, and in geranium the opposite was observed. At the end point of the trial the trend was the same in cyclamen and geranium, but in pansy the values show virtually no NO_3.

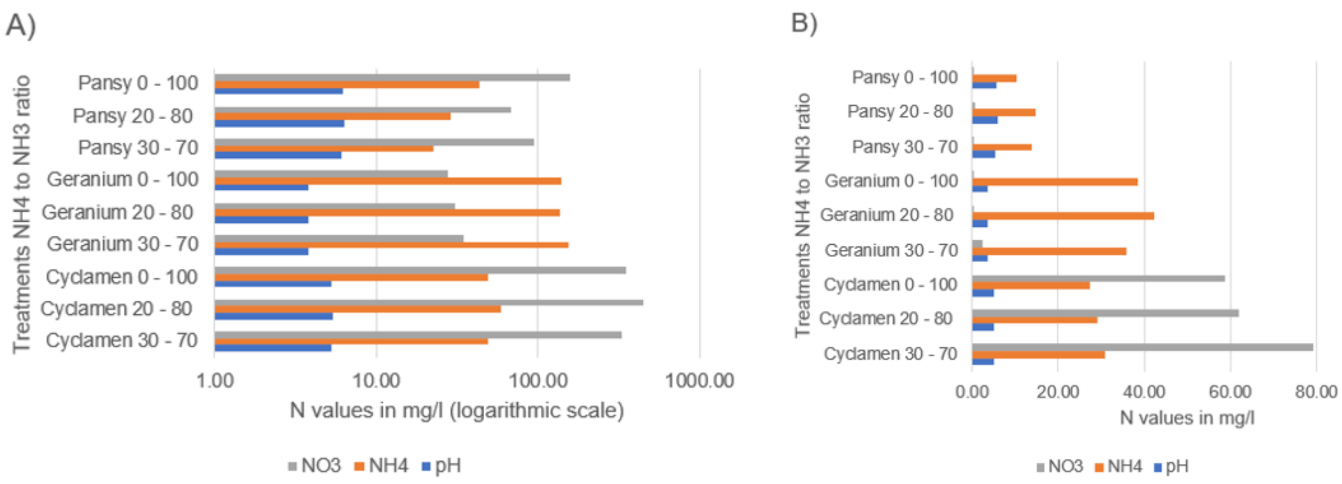
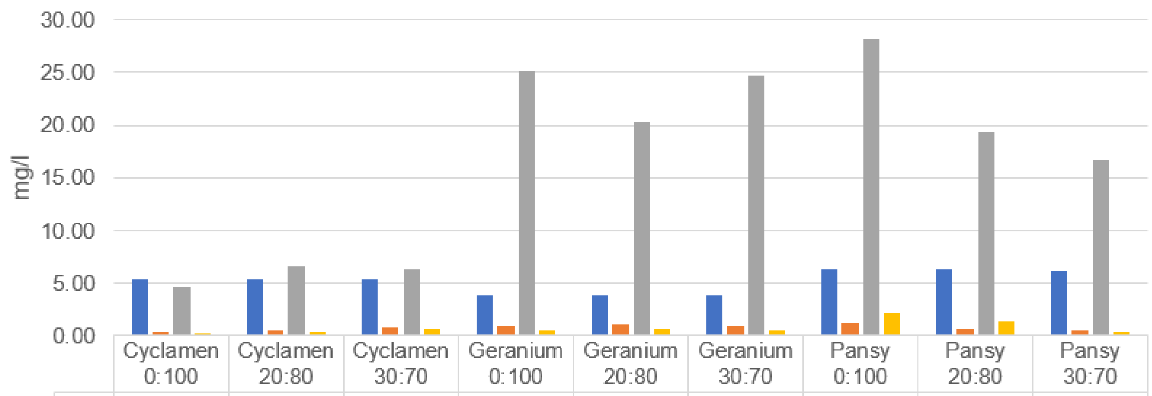


Figure 30. Results of leaf tissue analysis for NO_3, NH_4 and pH, samples from A) 17/07/2020 for mid-point observations, and B) 18/08/2020 for final observations.

The reduction of NO_3 to NH_4 produces positively charged hydrogen molecules which reduce cell pH, due to this we would anticipate the leaf tissue pH to be lowest where the results show the highest ratio of NH_4 to NO_3. The results from the trial confirm this trend.

The effect of pH on levels of micronutrient in the leaf tissue should show increased levels of molybdenum (Mo) with increasing pH and increasing Fe and Mn with decreasing pH as shown in Figure 31. The lower pH in geranium does show generally higher Fe and Mn; Mo is highest in pansy with the highest pH. However, the trend is not an exact correlation as pansy with the 100% NO_3 feed has the highest levels for all three nutrients and has the second highest pH.



	Cyclamen 0:100	Cyclamen 20:80	Cyclamen 30:70	Geranium 0:100	Geranium 20:80	Geranium 30:70	Pansy 0:100	Pansy 20:80	Pansy 30:70
pH	5.29	5.37	5.30	3.79	3.81	3.80	6.28	6.30	6.14
Fe	0.33	0.43	0.76	0.86	1.00	0.93	1.21	0.64	0.44
Mn	4.65	6.53	6.34	25.18	20.28	24.65	28.12	19.29	16.75
Mo	0.18	0.38	0.68	0.44	0.59	0.47	2.18	1.31	0.34

Figure 31. Leaf tissue analysis results for Fe, Mn and Mo in relation to pH, samples dated 17/07/2020.

Observations on plant size, number of flowers and fresh weight of above ground growth were taken during the trial. The data collected confirmed the visual conclusion that there was little impact on growth between the different treatments for each species, images from trial can be seen in Figure 32. In geranium, slightly greater plant height and fresh weight were observed in the 20:80 treatment, but no difference observed in flower stem number. In the three pansy treatments a slight increase in fresh weight was observed in the 0:100 treatment over the other two ratios, which was consistent with plant width observations at both the mid-point and end point of the trial. The full observation can be found in Tables 1, 2 and 3 of Appendix 17 of the report.

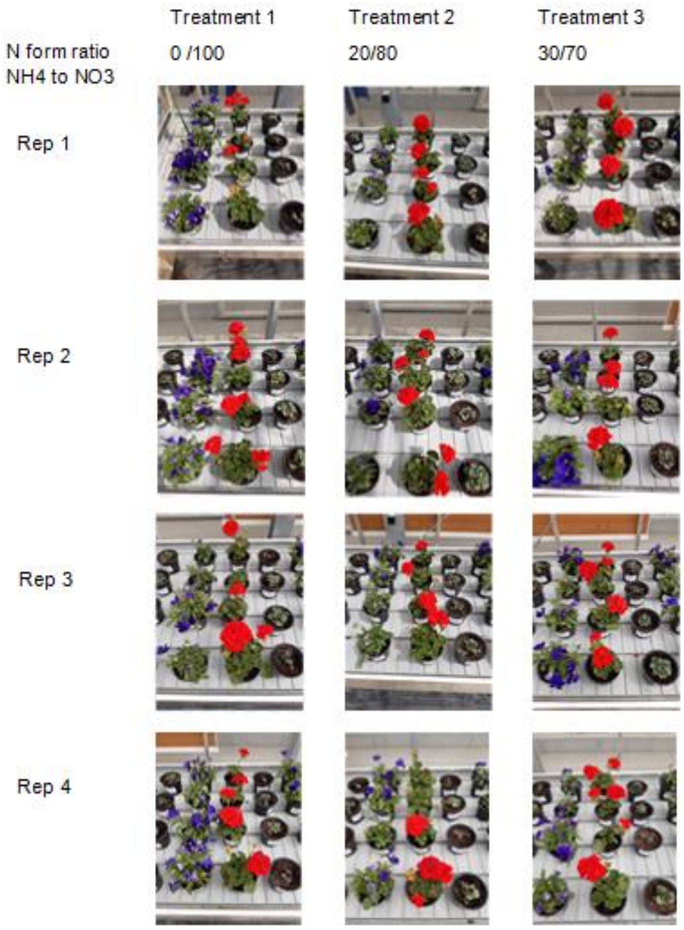


Figure 32. Trial images of all treatments dated 03/07/2020.

Discussion

The form that N is supplied to the plant in, either as a positively or negatively charged ion (NH_4^+ vs. NO_3^-), should influence the growing media pH as the plant exudes ions of the same charge during uptake. Feeds higher in positively charged NH_4 ions should see declining growing media pH and those higher in negatively charged NO_3 ions should see increasing pH.

In pansy the expected increase took place, but it was the same as in geranium, which was expected to have declining pH over the period of the trial. This should have been particularly obvious with the 30:70 treatment; the higher NH_4 content should give a greater decline in pH as the geraniums exude positive charged ions as the NH_4 is taken in.

From monitoring growing media pH in the trials of this project, it appears likely that the upward trend in growing media from the use of overhead irrigation and the water source (which is high in bicarbonate), has cancelled out the effect of the varying N-form ratios.

It is also possible that the ratios included in the trial are not sufficiently high in NH_4 to cause a significant decline in pH under the trial conditions. These ratios were selected as they are accessible to growers in the form of 'straights' or as part of prepared feeds; a higher NH_4 ratio may be detrimental in some crops but very unlikely to be used.

In contrast to the growing media, very different values for leaf tissue pH were observed. This was a reflection of the differences between species in the assimilation of NO_3 into NH_4 as part of normal metabolic processes. The low pH of the geranium leaf tissue correlates to the higher ratio of NH_4 to NO_3, and the opposite is true in cyclamen and pansy (Marschner 1994).

The impact of differences in ratio of NH_4 to NO_3 are more clearly demonstrated in other work carried out by NIAB in a separate commercial project, the results of which are reproduced here by kind permission of the customer. Plants of Petunia 'Surfinia® Purple' (Sunpurple) were grown in a range of commercially available and developmental peat-free growing medias. This was under the same glasshouse conditions as the experimental work for this project, using the same irrigation water, which is untreated mains water that is high in bicarbonate, no additional feed was applied. From the work in section 1 of this report looking at interactions between irrigation type in relation to the delivery of liquid feed, in petunia, with overhead watering and hard water it is expected that pH will rise over time.

Each of the growing medias in the trial was sampled and analysed in their unused condition and after 5 weeks of plant growth. Figure 33 below shows the values for pH at both points in the trial, and contrary to the expect trend, 2 treatments had a reduced pH level at the mid point of the trial. Treatments 13 and 14 showed a reduction of 1.2 and 1.4 respectively over the 5 week period. Treatment 18 did also have a reduction from 6.6 to 6.5 but in this context that was not considered of note as it would not have an impact of the availability of nutrients.

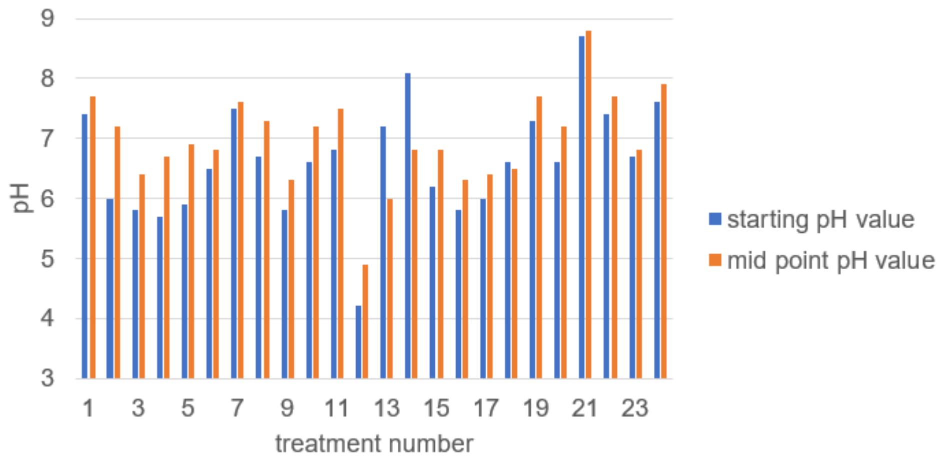


Figure 33. pH values obtained from laboratory analysis on a range of growing media products as unused material at the start of trial, samples dated 21/04/2021 and after 5 weeks of growth, samples dated 28/05/2021.

The extraction and analysis performed by NRM by adding a weight of sample equivalent to 60 ml volume to 300 ml of deionised water (ref BSEN 13652:2001).

When comparing these results with the values for N, these 2 growing media samples are the only ones that had a significantly higher proportion of NH_4 to NO_3 in the initial analysis, 3:1 in treatment 13, and in treatment 14 all N was in form of NH_4.

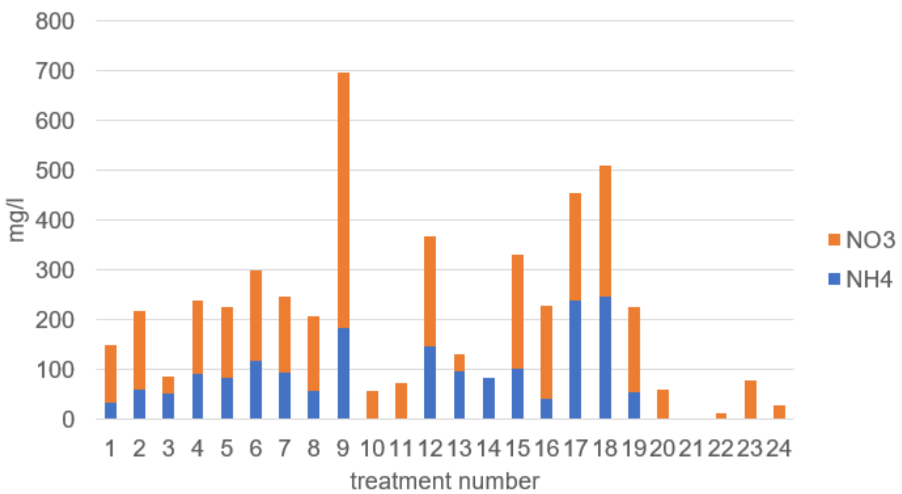


Figure 34. Results for N obtained from laboratory analysis on a range of growing media products as unused material at the start of trial, samples dated 21/04/2021.

Neither treatment 13 nor 14 has the highest total amount of NH_4 which highlights that it is the ratio that is of importance.

While the experimental work carried out as part of this project did not demonstrate the change in growing media pH as intended, the principle of changing the NH_4 to NO_3 ratio to influence pH is well document in other studies referenced in this report. Where pH is an issue in crops for nutrient availability, investigating the N-form ratio in liquid feeds and base fertilisers has value. For growers transitioning from peat-based growing media to peat-reduced and peat-free mixes, the ability to influence pH via the use of different forms of N could be of increasing relevance. Water retention in peat-reduced and peat-free mixes can be an issue, leading to more frequent or higher volume irrigation. If using water high in HCO_3^-, the increase in pH seen over time, would be exacerbated if no remedial action was taken. Using fertilisers higher in NH_4 or tailored to hard water (acidifying) are options to be considered to avoid problems with nutrient deficiency under high pH conditions.

Conclusions

- Readily available (in trade) fertiliser ratios of NH_4 and NO_3 are unlikely to impact on growing media pH in hard water areas when applied little and often.
- High alkaline irrigation water can eliminate the drop in pH that can occur through use of acidic feed, or when growing 'acidifying' plants (e.g., geranium).
- The addition of a base fertiliser in growing media with a higher proportion of NH_4 can induce a drop in pH over the short term when growing plants which are natural inclined to increase pH (e.g., petunia).
- Accumulation of higher NH_4 levels when using capillary matting may make the use of high ratio NH_4 feeds undesirable where crops species are inclined to reduced pH e.g., geranium.
- Results for pH in leaf tissue analysis and in the growing media of the same crop can be very different. It is important to understand both to identify the potential for deficiency and toxicity in different species.

Knowledge and Technology Transfer

How plants affect the rhizosphere during nutrient uptake – Talk by Hilary Papworth, AHDB event, Alternative growing media for ornamental plant production (10/07/2019)

Glossary

Cations (positive +ve) and anions (negative -ve) are charged particles. These ions are the 'form' of the element that the plant is taking up. The ratio of the different cations and anions can alter the pH of growing media.

The rhizosphere is the area (region) of soil/substrate directly around the root. It is the zone where plant, soil, nutrients, micro-organisms, water interact. The rhizosphere will differ slightly in terms of pH and EC, than the rest of the rootzone.

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Appendices

Appendix 15: Feed

Table 1. Feed calculations for 0:100 treatment

Liquid Feed specification 0:100				
Target	**Water**	**Feed**	**Feed & Water**	**ppm/mg/l (1:200 dilution)**
70ppm NO3-	8.5	92.04	100.54	100.54
30ppm NH4+	N/A	0	0	
45ppm P	1	44	45	45
125ppm K	2	115	117	117
8ppm Mg	3.6	4.4		8

Hortifeeds TE BEMIX - 1.50% B, 2.93% EDTA-Cu, 5.78% EDTA-Fe, 2.93% EDTA-Mn, 0.04% Mo and 1.04% EDTA-Zn.

Table 2. Feed calculations for 20:80 treatment

Liquid Feed specification 20:80				
Target	**Water**	**Feed**	**Feed & Water**	**ppm/mg/l (1:200 dilution)**
80ppm NO3-	8.5	73.1	81.6	99.7
20ppm NH4+	N/A	18.1	18.1	
45ppm P	1	44	45	45
125ppm K	2	123	125	125
8ppm Mg	3.6	4.4	8	8

Hortifeeds TE BEMIX - 1.50% B, 2.93% EDTA-Cu, 5.78% EDTA-Fe, 2.93% EDTA-Mn, 0.04% Mo and 1.04% EDTA-Zn.

Table 3. Feed calculations for 30:70 treatment

Liquid Feed specification 30:70				
Target	**Water**	**Feed**	**Feed & Water**	**ppm/mg/l , (1:200 dilution)**
70ppm NO3-	8.5	67.83	76.33	106.22
30ppm NH4+	N/A	29.89	29.89	
45ppm P	1	44	45	45
125ppm K	2	121.85	123.85	123.85
8ppm Mg	3.6	4.4	8	8

Hortifeeds TE BEMIX - 1.50% B, 2.93% EDTA-Cu, 5.78% EDTA-Fe, 2.93% EDTA-Mn, 0.04% Mo and 1.04% EDTA-Zn.

Appendix 16. Leaf tissue and growing media analysis results

Table 1. Observations on growing media pH and EC (SME) in cyclamen treatments.

pH level in growing media in Cyclamen treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	6.14	6.16	6.05
17/06/2020	6.15	6.11	6.04
24/06/2020	6	5.9	5
01/07/2020	5.23	5.14	5.15
15/07/2020	5.76	5.75	5.78
23/07/2020	6.33	6.36	6.33
30/07/2020	6.97	6.99	6.98
13/08/2020	6.31	6.34	6.13

EC (in µS) level in growing media in Cyclamen treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	1163	1244	1351
17/06/2020	1088	1621	1590
24/06/2020	1083	1938	1301
01/07/2020	1734	2850	2780
15/07/2020	1318	1361	1389
23/07/2020	690	670	656
30/07/2020	996	1154	1212
06/08/2020	758	1615	1968
13/08/2020	896	761	1253

Table 2. Observations on growing media pH and EC (SME) in geranium treatments.

pH level in growing media in Geranium treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	6.43	6.43	6.29
17/06/2020	6.18	6.17	6.17
24/06/2020	6	6	6
01/07/2020	5.23	5.24	5.22
15/07/2020	5.75	5.76	5.74
23/07/2020	6.81	6.87	6.72
30/07/2020	6.86	6.74	6.85
13/08/2020	7.12	6.86	7.34

EC (in µS) level in growing media in Geranium treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	1042	806	663
17/06/2020	546	1007	949
24/06/2020	488	636	464
01/07/2020	1276	896	1125
15/07/2020	362	268	312
23/07/2020	429	434	441
30/07/2020	639	521	439
06/08/2020	445	259	381
13/08/2020	218	344	220

Table 3. Observations on growing media pH and EC (SME) in pansy treatments.

pH level in growing media in Pansy treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	6.25	6.28	6.25
17/06/2020	6.12	6.14	6.17
24/06/2020	5.5	5.7	5.9
01/07/2020	5.52	5.42	5.33
15/07/2020	5.78	5.76	5.75
23/07/2020	6.81	6.87	6.72
30/07/2020	6.52	6.52	6.5
13/08/2020	7.48	7.37	7.55

EC (in µS) level in growing media in Pansy treatments			
Treatment	1	2	3
NH4:NO3 ratio	0-100	20-80	30-70
10/06/2020	1148	1692	1121
17/06/2020	873	956	775
24/06/2020	393	584	533
01/07/2020	989	1128	1578
15/07/2020	231	200	221
23/07/2020	250	224	237
30/07/2020	325	205	203
06/08/2020	205	212	262
13/08/2020	212	195	229

Table 4. Laboratory analysis of growing media.

Observations on Growing media analysis, sampled 03/07/2020

RESULTS (are expressed as mg/l)

Treatment name	NH4:NO3	pH	EC @20c	density	dry matter	dry density	Cl	P	K	Mg	Ca	Na	NH4	NO3	total sol N	S (SO4)	B	Cu	Mn	Zn	Fe
Cyclamen 3	30:70	5.6	616	602	25.1	151.1	132.5	84.3	255.4	159.4	116.6	73	<0.6	193.3	193.3	396.8	0.25	0.03	0.79	0.1	0.79
Cyclamen 2	20:80	5.7	575	632	23	145.4	150	77.4	248.9	141.4	102.3	77.3	4.1	153	157.2	376.1	0.26	0.04	0.61	0.1	0.56
Cyclamen 1	0:100	5.9	581	667	24.5	163.4	157.8	93.6	266.8	143	102.4	81.8	1	137.5	138.5	451.1	0.28	0.04	0.51	0.13	0.55
Geranium 3	30:70	5.9	390	639	23.5	150.2	114.9	49.3	114.9	93.8	70	75.4	2	54	56	474.3	0.33	0.04	0.33	0.27	0.71
Geranium 2	20:80	5.8	355	589	22.6	133.1	119	38.7	97.3	90.5	68.2	69.7	0.9	61.8	62.7	399.2	0.19	0.03	0.32	0.05	0.72
Geranium 1	0:100	5.8	409	612	22.1	135.3	133.6	43.1	114.7	106.8	83.5	74.5	0.8	87.2	88	416.8	0.21	0.02	0.39	0.11	0.65
Pansy 3	30:70	6.1	266	669	20.9	139.8	90.6	27.7	75.5	53.4	45.5	59.3	0.8	29.7	30.5	295.8	0.18	0.03	0.22	0.08	0.6
Pansy 2	20:80	6.2	186	688	20.2	139	82.7	26.7	65.6	46.5	43.9	60.3	1.4	21.1	22.5	298.5	0.17	0.02	0.18	0.04	0.55
Pansy 1	0:100	6.1	213	659	18.1	119.3	56.2	20.7	51.9	38.7	32.7	45.4	<0.6	19.1	19.6	231.8	0.15	0.03	0.16	0.06	0.45

Observations on Growing media analysis, sampled 03/07/2020

RESULTS (are expressed as mg/l)

Treatment name	NH4:NO3	pH	EC @20c	density	dry matter	dry density	Cl	P	K	Mg	Ca	Na	NH4	NO3	total sol N	S (SO4)	B	Cu	Mn	Zn	Fe
Cyclamen 3	30:70	5.9	301	412	31.1	128.1	92.5	43	66.7	65.3	62.3	50.6	1.8	46.5	48.3	266.4	0.19	0.02	0.07	<0.02	0.19
Cyclamen 2	20:80	6.1	313	445	26.6	118.4	113.3	46.1	91	62.7	58.9	59.6	6.1	50.3	56.3	260.6	0.22	0.02	0.02	0.03	0.15
Cyclamen 1	0:100	6.1	262	466	27.4	127.7	101.7	40.3	64.6	50.4	45.3	54.6	1.8	24.6	26.4	242.3	0.2	0.01	<0.01	<0.02	0.16
Geranium 3	30:70	6.5	142	545	24.7	134.6	65.6	7.2	6.1	18.8	22	41.2	1.3	<0.6	1.5	122.9	0.16	0.01	<0.01	<0.02	0.18
Geranium 2	20:80	6.4	128	450	24.6	110.7	59	5.1	7	15.7	19.6	32.7	1.4	0.9	2.3	115	0.13	0.02	<0.01	<0.02	0.17
Geranium 1	0:100	6.3	116	450	23	103.5	56.5	2.4	3.2	16	17.3	36.4	1.1	<0.6	1.1	108.5	0.11	<0.01	<0.01	<0.02	0.14
Pansy 3	30:70	6.6	96	450	28.2	126.9	29.6	2.8	7	7.3	10.4	35.6	2.4	3.7	6.1	84.5	0.1	0.02	<0.01	<0.02	0.23
Pansy 2	20:80	6.4	112	420	31.3	131.5	31.5	4.1	6.4	11.7	13.8	43.2	1.4	2	3.4	130.8	0.12	0.01	<0.01	<0.02	0.24
Pansy 1	0:100	6.4	140	444	28.9	128.3	43.4	6.1	9.3	16.9	21.5	50.7	1.7	2.7	4.4	164	0.1	0.01	<0.01	0.02	0.18

The extraction is performed by adding a weight of sample equivalent to 60mls volume to 300mls of deionised water (ref BSEN 13652:2001).

Table 5. Laboratory analysis of leaf tissue (SAP).

Observations on leaf tissue analysis, sampled 03/07/2020

RESULTS (are expressed as mg/l)

Treatment name	NH4:NO3	PH	NH_4	NO_3	Al	B	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
Cyclamen 3	30:70	5.30	49.68	327.78	0.26	3.33	696	0.56	0.76	5046	353.11	6.34	0.68	558.33	275.45	568.01	3.22
Cyclamen 2	20:80	5.37	59.28	445.50	0.24	3.87	737	0.23	0.43	5695	514.47	6.53	0.38	744.69	213.57	721.38	3.09
Cyclamen 1	0:100	5.29	49.26	349.02	0.27	3.82	513	0.18	0.33	4922	323.54	4.65	0.18	633.46	266.94	663.65	2.99
Geranium 3	30:70	3.80	153.90	34.98	0.31	4.38	73	0.42	0.93	2637	803.15	24.65	0.47	228.47	640.73	78.52	5.58
Geranium 2	20:80	3.81	136.14	31.08	0.41	4.15	148	0.45	1.00	2588	646.95	20.28	0.59	218.98	541.41	75.74	5.60
Geranium 1	0:100	3.79	139.98	28.02	0.39	4.26	200	0.30	0.86	3089	706.20	25.18	0.44	254.01	629.02	88.75	6.14
Pansy 3	30:70	6.14	22.68	95.10	0.17	2.61	947	0.28	0.44	2566	1284.09	16.75	0.34	77.11	875.67	382.99	2.30
Pansy 2	20:80	6.30	29.10	68.10	0.32	4.21	1064	0.43	0.64	2723	1382.82	19.29	1.31	109.91	822.10	399.03	3.50
Pansy 1	0:100	6.28	43.70	159.60	0.45	4.36	1498	0.96	1.21	3329	2038.50	28.12	2.18	114.83	1173.44	535.83	3.95

Observations on leaf tissue analysis, sampled 03/08/2020

RESULTS (are expressed as mg/l)

Treatment name	NH4:NO3	PH	NH_4	NO_3	Al	B	Ca	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
Cyclamen 3	30:70	5.23	30.96	79.37	0.22	4.16	688	0.08	0.34	6037	403.95	5.74	0.01	774.91	219.76	757.85	3.26
Cyclamen 2	20:80	5.12	29.10	62.09	0.16	3.83	509	0.07	0.28	5735	361.76	5.26	0.01	739.92	194.73	751.89	3.02
Cyclamen 1	0:100	5.24	27.24	58.67	0.17	3.84	476	0.08	0.25	5915	300.47	4.65	0.01	749.37	194.85	848.53	2.97
Geranium 3	30:70	3.73	36.00	2.57	0.36	4.99	548	0.15	0.87	2008	878.77	34.29	0.01	371.85	525.25	80.13	6.16
Geranium 2	20:80	3.57	42.24	0.37	0.34	4.96	580	0.14	0.88	1717	968.06	36.21	0.01	434.17	544.45	84.35	5.25
Geranium 1	0:100	3.66	38.52	0.14	0.27	4.35	240	0.09	0.55	1575	807.94	28.60	0.01	357.40	477.42	66.97	4.80
Pansy 3	30:70	5.43	13.98	0.43	0.10	2.27	1060	0.29	0.35	1350	1070.35	15.56	0.12	91.35	446.45	173.82	2.45
Pansy 2	20:80	5.97	14.88	0.72	0.14	2.37	1056	0.41	0.48	1416	1052.61	17.20	0.30	105.88	407.30	134.76	2.68
Pansy 1	0:100	5.74	10.26	0.34	0.13	2.18	881	0.24	0.32	799	862.37	14.16	0.19	79.82	322.53	120.91	2.36

Appendix 17: Trial observations and data

Table 1. Observations on geranium.

Geranium plant height observations in mm 03/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	170	145	170
	95	130	130
	130	130	175
	160	175	175
	165	160	140
	160	165	145
	170	160	140
	175	130	175
	180	160	165
	160	160	140
	140	170	155
	190	130	165
	160	150	185
	140	150	155
	130	190	155
	145	175	160
	160	170	150
	140	210	180
	135	150	120
	165	160	150
	130	150	155
	150	150	160
SE	21.3	19.9	16.6
Average	152.3	157.7	156.6

Geranium plant height observations in mm 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	172	205	175
	175	255	203
	245	221	150
	228	229	235
	190	255	205
	170	130	165
	195	175	190
	145	225	245
	150	240	180
	180	185	220
	180	196	155
		200	185
SE	29.9	36.0	30.3
Average	184.5	209.7	192.3

Geranium number of flower observations, 03/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	3	2	3
	3	4	2
	4	2	5
	3	2	3
	2	3	2
	2	3	2
	3	4	2
	3	1	2
	2	2	4
	1	3	2
	2	2	2
	4	1	2
	2	5	3
	2	2	2
	3	2	2
	4	2	3
	4	2	2
	1	3	3
	2	2	2
	1	3	2
	3	3	2
		1	3
SE	1.0	1.0	0.8
Average	2.6	2.5	2.5

Geranium number of flower observations, 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	3	4	5
	3	7	4
	5	4	3
	7	6	7
	3	4	3
	5	3	4
	5	4	9
	4	8	7
	4	4	6
	3	6	3
	3	5	5
	6	4	
SE	1.4	1.5	2.0
Average	4.3	4.9	5.1

Geranium fresh weight observations in grams, 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	48	58	58
	64	83	57
	67	50	44
	69	64	67
	46	37	55
	49	49	36
	61	33	62
	43	81	58
	54	71	39
	54	58	51
	47	59	41
	50	50	54
SE	8.8	15.5	9.7
Average	54.3	57.8	51.8

Table 2. Observations on cyclamen.

Cyclamen plant width observations in mm 03/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	60	65	80
	75	65	70
	50	111	75
	72	96	83
	71	91	79
	91	80	90
	95	100	95
	90	87	73
	60	78	83
	100	70	67
	96	75	74
	67	83	76
	70	76	76
	74	80	69
	60	80	74
	80	66	76
	82	45	100
	80	62	80
	102	80	76
	81	82	60
	66	70	93
			72
SE	14.5	14.4	9.5
Average	77.2	78.2	78.2

Cyclamen plant width observations in mm 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	88	80	140
	131	76	130
	172	170	160
	135	163	160
	95	140	118
	160	125	100
	130	150	147
	155	138	120
	132	114	142
	106	136	126
			132
			72
SE	27.7	31.6	24.9
Average	130.4	129.2	128.9

Cyclamen leaf number observations 03/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	3	9	20
	4	4	4
	2	21	17
	9	19	24
	20	25	14
	5	15	27
	19	24	32
	22	13	15
	4	16	21
	21	12	18
	16	17	12
	3	15	16
	14	8	15
	17	7	11
	3	13	10
	15	4	20
	10	16	22
	10	8	16
	15	12	11
	6	12	7
	14		17
	12		5
SE	6.6	5.9	6.9
Average	11.1	13.5	16.1

Cyclamen fresh weight observations in grams, 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	10	5	29
	31	7	25
	41	56	44
	35	48	45
	14	27	21
	46	19	17
	35	34	24
	29	28	17
	26	24	35
	33	10	25
			24
			8
SE	11.1	16.9	10.9
Average	30.0	25.8	26.2

Cyclamen number of flower observations, 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	9	0	3
	0	0	0
	5	9	0
	1	9	10
	13	1	0
	0	0	3
	9	0	7
	0	1	0
	6	4	0
	0	5	7
			1
			2
SE	4.8	3.8	3.4
Average	4.3	3.6	2.8

Table 3. Observations on pansy.

Pansy plant width observations in mm 03/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	200	160	180
	220	180	165
	250	160	180
	220	185	160
	170	145	230
	225	170	200
	230	210	210
	140	180	140
	200	150	200
	225	180	190
	170	190	190
	150	210	195
	190	165	140
	220	135	260
	165	190	130
	210	185	155
	205	210	165
	185	130	185
	185	170	180
	170	140	190
	170	195	190
	140	145	150
SE	30.8	24.4	30.3
Average	192.7	172.0	181.1

Pansy plant width observations in mm 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	330	245	320
	320	210	375
	365	325	310
	315	240	365
	330	350	300
	340	345	320
	320	320	240
	300	355	300
	290	320	230
	300	200	330
	280	300	300
	300	195	205
SE	22.0	61.5	51.5
Average	321.0	283.8	299.6

Pansy flower number observations 3/07/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	5	3	5
	5	4	2
	6	0	5
	0	2	8
	7	2	11
	9	3	3
	10	5	7
	1	3	0
	2	2	5
	7	4	4
	2	5	3
	1	6	7
	9	4	2
	8	1	6
	2	6	2
	8	6	5
	10	8	2
	4	4	4
	8	2	6
	8	0	4
	11	4	3
	3	1	4
SE	3.4	2.1	2.4
Average	5.7	3.4	4.5

Pansy fresh weight observations in grams, 03/08/2020

	Treatment 1	Treatment 2	Treatment 3
N form ratio NH4:NO3	0 - 100	20 - 80	30 - 70
Observations	121	122	116
	87	87	114
	133	90	101
	106	102	111
	116	91	115
	73	110	78
	111	99	67
	121	115	83
	96	89	94
	111	63	77
	109	90	83
	80	85	72
SE	18.0	15.7	18.2
Average	105.3	95.3	92.6

