**Project title:** The Bedding and Pot Plant Centre – new product opportunities for bedding and pot plant growers.

***Objective 3:*** *To investigate plant nutrition, water quality and environment as possible causes of necrotic spotting and associated symptoms in susceptible Verbena varieties.*

**Project number:** PO 019a

**Project leader:** Dr Jill England, ADAS Boxworth

**Report:** Annual report, 31 March 2018

**Previous report:** None

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Chloe Whiteside (ADAS), Horticulture Consultant

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**Location of project:** Woodlands Nursery, Stapleton, Leicestershire

**Industry Representative:** Caroline Shove, Bryants Nurseries Ltd, Water Lane, Bovingdon, Hemel Hempstead, Hertfordshire, HP3 0NA

**Date project commenced:** 1 April 2017

**Date project completed (or expected completion date):** 31 March 2019

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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.

Dr Jill England

Senior Horticulture Consultant

ADAS

Signature Date 31 March 2018

Chloe Whiteside

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**Report authorised by:**

Dr Barry Mulholland

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ADAS

Signature Date 31 March 2018

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# Contents



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# Grower Summary

## Headline

- The incidence of necrotic leaf spot and chlorosis is greater in plants grown in 'wet' growing media and 'ambient' environment conditions (higher VPD).
- Root quality poorer under 'wet', humid conditions.
- Water quality and growing media pH had no effect on symptom development.

## Background

The Bedding and Pot Plant Centre (BPPC) has been established to address the needs of the industry via a programme of work to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries. Knowledge transfer events including trial open days and study tours are also included in the programme.

The work programme is guided by a grower-led Management Group that includes members of the BPOA Technical Committee, and representatives from Baginton Nurseries, Coventry the host nursery for the BPPC, and growers representing both the bedding and pot plant sectors.

*This is the Bedding and Pot Plant Centre report for:*

***Objective 3:*** *To investigate plant nutrition, water quality and environment as possible causes of necrotic spotting and associated symptoms in susceptible Verbena varieties.*

## Summary

Leaf problems have been encountered with *Verbena* at various nurseries, including chlorotic leaf margins and necrotic spotting (**Figure 1**). No pathogen has been associated with the symptoms. Although two trials were carried out in 2016 to evaluate the influence of watering regime (dry, standard, wet), pH (4.5, 5.8 and 6.5) and trace element delivery (fritted and unfritted) on symptom development in *Verbena* 'Quartz Blue', *V*. 'Obsession Scarlet' and *V*. 'Temari Blue', none of the *Verbena* varieties developed symptoms and the cause of the spotting and chlorosis remains unknown.

**Figure 1.** *Verbena* with marginal chlorosis (left) and leaf spot (right) symptoms

Plug plants of *Verbena* 'Quartz Blue' (PanAmerican, seed raised) were delivered to Woodland Nursery, Stapleton, Leicestershire and transplanted into six packs (black plastic) containing growing media, pre-adjusted to pH 4.5 and 6.5 (supplied by Bulrush Horticulture Ltd.) in week 19 (10 May, 2017). The plants were grown on under glass for one week before additional treatments were applied, and during this phase of the trial, plants were irrigated using a 50:50 blend of rainwater and borehole water. Treatments (**Table 1**), set up on 17 May 2017, were: 1) three water quality treatments were applied: rainwater, borehole water and a 50:50 mix of rainwater and borehole water. For the 50:50 treatment, a quantity of water was prepared at the start of the trial and used throughout, and 2) two water management regimes, which were achieved by managing the irrigation frequency; the dry treatment plants were watered as necessary to prevent the plants from wilting. The wet treatment was watered more frequently to maintain a wet regime. Both were determined by grower knowledge and were watered by a nominated person throughout the trial, and 3) two environment treatments; for the humid environment treatment, plants were sited under 'tents' of milky white propagation plastic (**Figure 2**).

**Figure 2.** Trial at set up (left) and environment monitoring equipment (right).

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**Table 1.** *Verbena* leaf spot and chlorosis trial treatment list

| T | Irrigation regime | Water quality | Environment | pH |
|---|---|---|---|---|
| 1 | Wet | Borehole | Humid | Low (4.5) |
| 2 | | | | High (6.5) |
| 3 | | | Ambient | Low (4.5) |
| 4 | | | | High (6.5) |
| 5 | | Rainwater | Humid | Low (4.5) |
| 6 | | | | High (6.5) |
| 7 | | | Ambient | Low (4.5) |
| 8 | | | | High (6.5) |
| 9 | | 50/50 blend of borehole and rainwater | Humid | Low (4.5) |
| 10 | | | | High (6.5) |
| 11 | | | Ambient | Low (4.5) |
| 12 | | | | High (6.5) |
| 13 | Dry | Borehole | Humid | Low (4.5) |
| 14 | | | | High (6.5) |
| 15 | | | Ambient | Low (4.5) |
| 16 | | | | High (6.5) |
| 17 | | Rainwater | Humid | Low (4.5) |
| 18 | | | | High (6.5) |
| 19 | | | Ambient | Low (4.5) |
| 20 | | | | High (6.5) |
| 21 | | 50/50 blend of borehole and rainwater | Humid | Low (4.5) |
| 22 | | | | High (6.5) |
| 23 | | | Ambient | Low (4.5) |
| 24 | | | | High (6.5) |

T = Treatment

***Summary of results***

**Environmental conditions** had the strongest influence with more symptoms developing in plants grown under ambient conditions.

A closer look at the environmental conditions indicated that VPD (vapour pressure deficit) was generally below 0.5 kPa in the humid environment, and approaching or above 1.0 kPa in the ambient treatments. VPD between 0.4 kPa and 1.2 kPa is generally considered a target range for bedding plant production, with lower values more appropriate to plants during propagation or early growth, and higher values for late vegetative growth onwards. High VPD (>1 kPa) imparts a strong drying effect on plants, while at 0.0 kPa VPD the air is fully saturated. Plant stress can be moderated through ensuring that plants are not produced under high VPD conditions; the appropriate VPD range varying according to plant species. For the plants in this trial, fewer symptoms developed in plants grown under generally low VPD conditions.

**Irrigation regime** also had a strong influence on symptom development in this trial, with more symptoms developing in plants grown under the wet regime.

**Water quality** did not have a clear influence on symptom development in this trial. It had been expected that more symptoms would develop in plants irrigated with the high EC borehole water. However, the proportion of plant cover with symptoms was greater in plants irrigated

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with the 50:50 blend water than either borehole water or rainwater. The number of plants per plot with symptoms was similar for all water quality treatments.

**Growing media pH** did not influence symptom development in this trial.

Irrigation regime and environment were the strongest influences; with greater symptom development, in wet, ambient conditions. The 'ideal' environment appears to be somewhere between the two growing environments that were tested; 'Ambient' was too dry for *Verbena* and some wetting of paths would help to reduce symptoms. Consideration of VPD may enable growers to determine a range within which symptoms do not develop, striking a balance where plants are sufficiently active (i.e. transpiring sufficiently to take up adequate nutrients and water, and to regulate plant temperature) to maintain quality without symptoms developing.

Growing media moisture influences root development, with fewer roots and root hairs present in plants grown under wet conditions, limiting the ability of plants to respond during stress conditions such as high light, temperature and VPD. Growing media should not remain wet for long periods of time and should be allowed to dry sufficiently before watering. Good root development will produce plants with more resilience against sharp increases in VPD and temperature.

## Action points

- Take care when irrigating crops. Allow growing media to dry back before watering, and ensure that it does not remain wet for long periods as this will have a negative impact on root structure, plant growth and quality.
- Weighing containers to give an indication of growing media moisture content before and after irrigation may be useful to set irrigation guidelines and as a basis for staff training.
- Consider monitoring VPD and determine a range within which fewer symptoms appear, and plant quality is improved.

## Financial benefits

The incidence of marginal leaf chlorosis and necrotic spotting symptoms vary from year to year, ranging from one or two varieties up to 60% of varieties in some years; the problem can affect 100% of the crop. While the exact value of *Verbena* to the bedding plant sector is not known, grower feedback suggests that 5-6% of spring bedding sales can be affected. To put this into context, many nurseries consider 3% waste as the upper acceptable limit and above this would stop producing a particular crop or variety. Symptoms have been reported on many nurseries across the sector.

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As an example, the turnover associated with a batch of 10,000 *Verbena* double six packs (12 plants) is estimated at £22,000 to the grower. Where 60% of the crop is affected, the value of this wastage is estimated at £13,200.

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# Science Section

## Introduction

The Bedding and Pot Plant Centre (BPPC) has been established to address the needs of the industry via a programme of work to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries. Knowledge transfer events including trial open days and study tours were also included in the programme.

The work programme is guided by a grower-led Management Group that includes members of the BPOA Technical Committee and representatives from Baginton Nurseries, Coventry the central host nursery for the BPPC. The agreed objectives for the Bedding and Pot Plant Centre, 2017-18 were:

**Objective 1:** To evaluate a range of plant growth regulators (PGRs) either approved in the UK or in other European Countries for use on bedding and pot plants (spray and drench application).

**Objective 2:** To evaluate a range of products alone or in combination, to increase the success rate and reduce rooting time when striking un-rooted cuttings. This is a continuation of work carried out in 2016.

**Objective 3:** To evaluate plant nutrition, water quality, irrigation regime and environment as possible causes of necrotic spotting and associated symptoms in susceptible *Verbena* varieties. This is a continuation of work carried out in 2016.

**Objective 4:** To extend the marketing season for coloured varieties of pot-grown Hellebore to include the months prior to the New Year through cool treatments.

**Objective 5:** To evaluate the shelf life performance of micro-propagated Hellebores produced as pot plants for pre-Christmas marketing.

**Objective 6:** To evaluate a range of plant growth regulators (PGRs) and fungicides either approved in the UK or in other European countries for spray application on Poinsettia.

*This is the Bedding and Pot Plant Centre report for Objective 3.*

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## Background

Problems have been encountered with *Verbena* plant quality at various nurseries. Symptoms are reported to appear in propagation prior to transplant when a minimal amount of liquid feed has been applied, and also as plants proceed to flowering. Both seed and cutting raised plants may be affected. Symptoms include:

1. Necrotic margins on older leaves and leaf yellowing which can work upwards to younger foliage. Necrotic spots have also been seen on leaves, from which it has not been possible to isolate any pathogens. These symptoms are generally worse in blue varieties from both seed and cutting raised material.

2. Chlorosis starting from the top of the plant and moving down; starting towards the middle of the leaf and spreading out.

Interpretation of growing media and water analyses provided by nurseries where *Verbena* have been affected by these issues suggests that the variable quality of irrigation water (in terms of conductivity, particularly as influenced by the level of chloride, sulphates etc., and alkalinity) may influence the development of symptoms (mains water suppliers can routinely change the water source at various times of year depending on water table levels). In addition to this, problems have variously been attributed to transient iron deficiency and manganese toxicity; manganese is more available, potentially at toxic levels below pH 5 whilst iron can become deficient in high pH depending on the plant sensitivity.

Fritted trace elements are less soluble than inorganic trace elements, therefore available to plants more slowly and over a longer period of time, providing less potential for toxicity problems (plants have to work harder to access nutrients). Bulrush Horticulture has reported success in using fritted trace elements to ameliorate manganese deficiency in brassicas and so their use was examined in the 2016 trial. Growing conditions were also investigated via three irrigation regimes (standard, wet and dry). Spring and summer trials were undertaken to identify any effect of light/temperature on symptom expression.

In 2016, two trials were carried out to evaluate the influence of watering regime (dry, standard, wet), pH (4.5, 5.8 and 6.5) and trace element delivery (fritted and unfritted) in spring and summer 2016 on symptom development in *Verbena* 'Quartz Blue' (spring and summer trials); and *V*. 'Obsession Scarlet' and *V*. 'Temari Blue' (summer trial only). However, none of the *Verbena* varieties developed symptoms and the cause of spotting and chlorosis remains unknown.

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A further trial was carried out in 2017 to evaluate the influence of water quality and environment on symptom development under a range of water management and pH regimes.

**Objective 3:** To evaluate plant nutrition, water quality, irrigation regime and environment as possible causes of necrotic spotting and associated symptoms in susceptible *Verbena* varieties.

**Specific objective 1**. To evaluate the effect of two growing media pH levels (4.5 and 6.5), representing low and high values for *Verbena* production, on the occurrence of necrotic leaf spotting and associated symptoms in *Verbena.*

**Specific objective 2**. To evaluate the effect of water quality (borehole, rainwater and 50/50 blend) on the occurrence of necrotic leaf spotting and associated symptoms in *Verbena.*

**Specific objective 3**. To evaluate the effect of environment (ambient and humid) on the occurrence of necrotic leaf spotting and associated symptoms in *Verbena.*

**Specific objective 4**. To evaluate any link between growing media moisture (wet/dry) on the occurrence of necrotic leaf spotting and associated symptoms in *Verbena*.

**Specific objective 5**. To evaluate the influence of fluctuating water quality on the occurrence of necrotic leaf spotting and associated symptoms through water monitoring and analysis.

## Methods and materials

*Site and crop production details*

Plug plants of *Verbena* 'Quartz Blue' (PanAmerican, seed raised) were delivered to Woodland Nursery, Stapleton, Leicestershire and transplanted into six packs (black plastic) containing growing media, pre-adjusted to pH 4.5 and 6.5 (supplied by Bulrush Horticulture Ltd.) in week 19 (10 May, 2017). The plants were grown on under glass for one week before treatments were applied. During this phase of the trial, plants were irrigated using a 50:50 blend of rainwater and borehole water. Treatments (**Table 2**) were set up on 17 May 2017:

- Three water quality treatments were applied: rainwater, borehole water and a 50:50 mix of rainwater and borehole water. For the 50:50 treatment, a quantity of water was prepared at the start of the trial and used throughout.
- The two water management regimes were achieved by managing irrigation frequency; the dry treatment plants were watered as necessary to prevent the plants from wilting. The wet treatment was watered more frequently to maintain a wet regime. Both were determined by grower knowledge and were watered by a nominated person throughout the trial (**Appendix 1A**).

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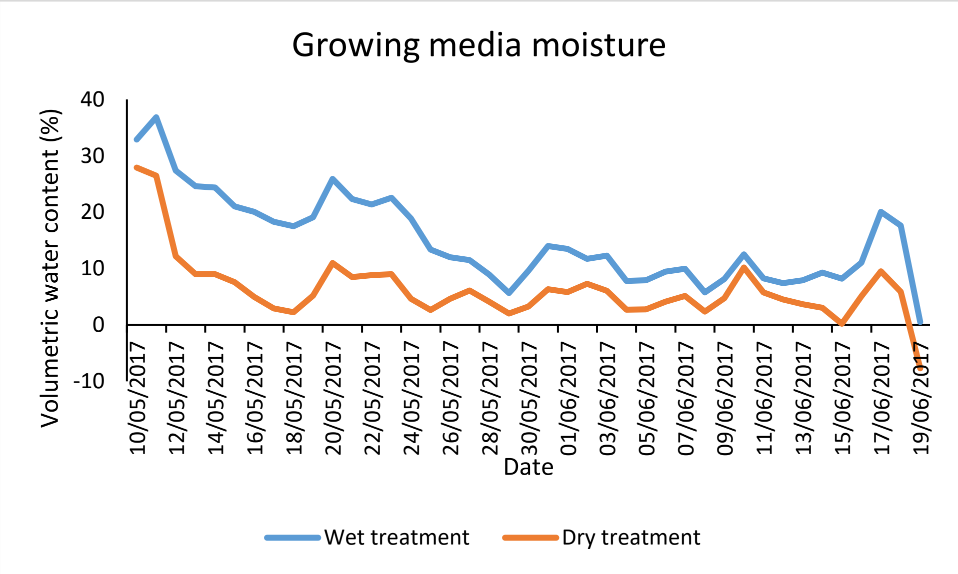
- For the humid environment treatment, plants were sited under ‘tents’ of milky white propagation plastic (**Figure 3**).

Temperature and humidity were recorded every 30 minutes using three Watchdog 1000 series microstation data loggers (**Figure 3** and **Appendix 1A**

Growing media moisture




**Appendix 1B**). In addition, growing medium moisture was monitored for each of the two water management treatments using a WaterScout SM100 soil moisture sensor (one for each treatment) (**Appendix 1A**).

Plants were monitored for the development of symptoms attributed to nutritional disorders and a full assessment was carried out on 19 June 2017, week 25 (**Table 3**). Water, growing media and plant tissue samples were submitted to Natural Resource Management (NRM) for analysis at the start and end of the trial **(Appendix 2A** - **Unused and** used. W = wet; BH = borehole; AMB = ambient; S = symptoms; NS = no symptoms

**Appendix 2C**).

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**Figure 3.** Trial at set up (left) and environment monitoring equipment (right).

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**Table 2.** *Verbena* leaf spot and chlorosis trial treatment list

| T. | Irrigation regime | Water quality | Environment | pH |
|---|---|---|---|---|
| 1 | Wet | Borehole | Humid | Low (4.5) |
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| 5 | | Rainwater | Humid | Low (4.5) |
| 6 | | | | High (6.5) |
| 7 | | | Ambient | Low (4.5) |
| 8 | | | | High (6.5) |
| 9 | | 50/50 blend of borehole and rainwater | Humid | Low (4.5) |
| 10 | | | | High (6.5) |
| 11 | | | Ambient | Low (4.5) |
| 12 | | | | High (6.5) |
| 13 | Dry | Borehole | Humid | Low (4.5) |
| 14 | | | | High (6.5) |
| 15 | | | Ambient | Low (4.5) |
| 16 | | | | High (6.5) |
| 17 | | Rainwater | Humid | Low (4.5) |
| 18 | | | | High (6.5) |
| 19 | | | Ambient | Low (4.5) |
| 20 | | | | High (6.5) |
| 21 | | 50/50 blend of borehole and rainwater | Humid | Low (4.5) |
| 22 | | | | High (6.5) |
| 23 | | | Ambient | Low (4.5) |
| 24 | | | | High (6.5) |

T = Treatment

*Pesticide applications*

Plants were monitored for pests and disease throughout. The following fungicide and insecticide treatments were applied:

Aphid and *Botrytis*: Chess (as pymetrozine, EAMU 2016/13) and Amistar (as azoxystrobin, EAMU 0965/17) applied as a tank mix on 29 May (week 22, 1 application).

*Trial design and statistical analysis*

Treatments consisted of four factors; environment, irrigation regime, water quality and growing medium pH (**Table 2**). The trial was arranged in a restricted randomised split-split-split-plot design with 24 treatments replicated four times, resulting in 96 plots and 1152 plants in total. Plots consisted of two 6-packs.

Results were examined by ANOVA with use of Duncan's multiple range test to separate treatments.

*Assessments*

Inspections and assessments are summarised in **Table 3** and below.

Plug plants were assessed for quality and consistency prior to potting.

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Final assessment:

- Plant height of three plants per plot.
- Plant quality for each plot as a whole, scored on a scale of 0 – 3: 0 = dead, 1 = poor, not marketable, 2 = good, marketable, 3 = excellent, marketable.
  - Root quality, scored on a scale of 0 - 4 for 3 plants per plot: 0 = no root development, 1 = rooting in up to 25% of cell, 2 = rooting in 26 – 50% of cell, 3 = rooting in 51 – 75% of cell, 4 = rooting in 76 – 100% of cell.
  - Percentage plant cover per plot affected by symptoms.
  - Number of plants per tray affected by symptoms.

**Table 3.** Summary of inspections and assessments, 2017

| Date | Week no. | Action |
|---|---|---|
| 10 -11 May | 19 | Transplant date |
| 15 May | 20 | Foliage samples submitted for analysis |
| 17 May | 20 | Humid treatments set up. Water quality and water management treatments started. Water and growing media samples submitted for analysis |
| 23 May | 21 | Inspection |
| 30 May | 22 | Inspection |
| 07 June | 23 | Inspection |
| 19 June | 25 | Final assessment. Plant height and root development, symptom severity (% of plot affected, number of plants per plot affected) |
| 21 June | 25 | Foliar and growing media samples submitted for analysis. |

## Results

### *Pre-transplant*

Prior to transplant, a sub-sample of *Verbena* 'Quartz Blue' plugs were assessed for plant quality (score 9.0), root quality (fully rooted with healthy white roots) and height (average 25 mm), and were determined to be healthy and suitable for transplant (**Figure 4**).

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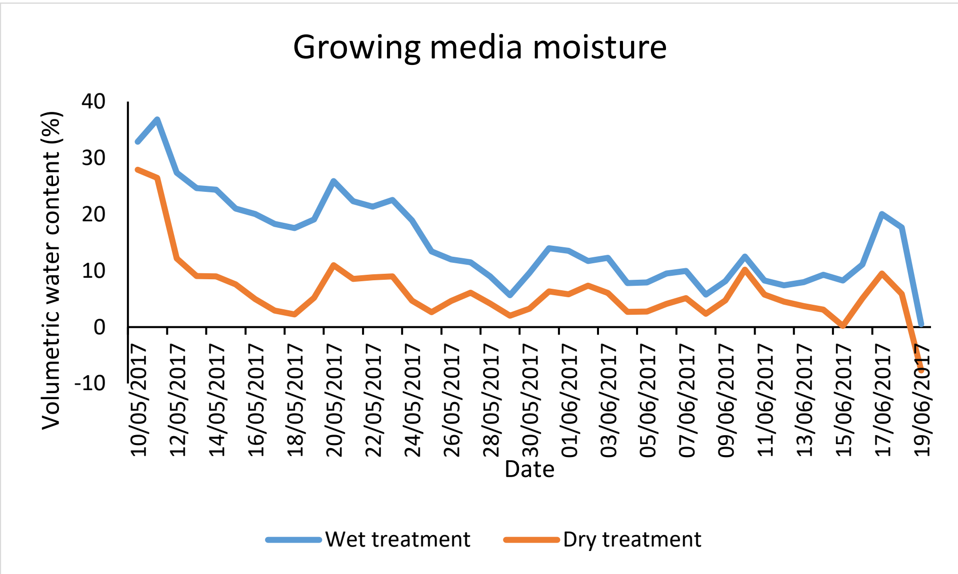
**Figure 4.** *Verbena* ‘Quartz Blue’, pre-transplant assessment, 10 May 2017 (week 19).

***Post-transplant***

Temperature and humidity in the humid and ambient environments were monitored throughout, and VPD calculated (**Appendix 1A**

Growing media moisture




**Appendix 1B**). Volumetric moisture data confirmed the different moisture levels in the wet and dry treatments (**Appendix 1A**). Water analyses carried out at the start of the trial confirmed conductivities of 2264.16 uS/cm (borehole water), 875.47 uS/cm (50:50 blend) and 11.05 uS/cm (rainwater) (**Appendix 2A**). **Figure 5** indicates representative images of the marginal chlorosis and leafspot symptoms that were assessed.

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In general terms, plants grown under the humid environment were generally leggy, weak and pale compared to ambient treatments, as might be expected. There was no single treatment where plants were deemed marketable.

**Figure 5.** Verbena with marginal chlorosis (left) and leaf spot (right) symptoms

*Plant height*

Plants were generally taller in the humid, wet, high pH treatments, and shorter in the dry, ambient, low pH treatments, as might be expected. There was no difference in plant height due to water quality. Overall, plants in the humid treatments were significantly taller than those grown in the ambient treatments ($p<0.001$) (**Table 4**). Similarly, plants in the wet treatments were significantly taller than those in the dry treatments ($p<0.001$). Whilst taller than in other treatments, the plants grown under humid conditions were also generally leggy, pale and weak.

*Root quality*

Root quality was generally poorer in the humid, wet treatment. Overall, root quality was significantly poorer in both the wet treatment than the dry treatment ($p<0.001$), and in the humid environment than the ambient environment ($p<0.001$). Of these treatments, root quality was significantly poorer in the wet, humid treatment than all other combinations (wet, ambient; dry, humid and dry ambient) ($p<0.001$).

Considering water quality; root quality was significantly poorer in plants watered with either the borehole water or the 50:50 blend water under humid conditions than ambient ($P=0.011$).

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No other treatment differences were statistically significant (all water quality treatments under ambient conditions, and plants watered with rainwater under humid conditions).

Considering water management; root quality was significantly poorer in plants grown under wet conditions in the humid environment when watered with either the borehole water or the 50:50 water quality blend ($p<0.05$). No other treatment differences were statistically significant.

There were no significant differences in root quality due to growing media pH.

*Number of symptomatic plants per plot*

Overall, significantly more plants per plot were affected when grown in the ambient environment than the humid environment ($p<0.001$). There was interaction between the water management and environment treatments, with significantly fewer plants per plot with symptoms when grown under wet, humid conditions than all other treatment combinations (wet, ambient; dry, ambient; and dry, humid treatments) ($p<0.001$). The number of symptomatic plants per plot was not significant for any other treatment combinations.

*Proportion of plant cover per plot with symptoms*

Percentage plant cover was a measure of the proportion of each plot with symptoms. Overall, a significantly greater proportion of each plot was affected in the wet treatments than the dry treatments ($p<0.001$), and in the ambient environment than the humid environment ($p<0.001$). Again, there was interaction between treatments, with a significantly greater proportion of plant cover in each plot affected under the wet, ambient conditions than all other treatments (the dry, ambient; dry, humid; and wet humid treatments) ($p<0.001$). Considering water quality, a significantly greater proportion of each plot was affected in plants irrigated with the 50:50 water blend than the borehole water ($p<0.05$), but not the rainwater (which was not significantly different than either the borehole water or the 50:50 blend).

*Growing media pH*

Initial growing media analyses confirmed treatment pH as: pH 4.1 (low) and pH 5.5 (high) (**Appendix 2B**). Tissue and growing media samples were taken from symptomatic and non-symptomatic plants from affected plots on 21 June 2017 and were submitted to NRM for analysis (**Appendix 2B** and **Unused and** used. W = wet; BH = borehole; AMB = ambient; S = symptoms; NS = no symptoms

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**Appendix 2C**). The growing media analyses indicate that the pH of these low pH treatments were <4.2 and the pH of the high pH treatments were >5.4 at the end of the trial, and there had been minimal drift in pH during the trial.

However, none of the assessments recorded statistically significant differences due to growing media pH. In addition to this, neither the growing media nor the plant tissue analyses indicated levels of any nutrients outside the recommended range for bedding plants.

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**Table 4.** Mean plant quality, plant height, root quality, number of plants per plot affected and proportion of plant cover in plot affected, 19 June 2017, 5 weeks after the treatments were applied

| Treatment | | | | | Mean plant quality | Mean plant height (mm) | Mean root quality | Mean no. plants per plot affected | Mean plant cover in plot affected (%) |
|---|---|---|---|---|---|---|---|---|---|
| **T** | **Irrigation regime** | **Water quality** | **Environment** | **pH** | | | | | |
| 1 | Wet | Borehole | Humid | Low (4.5) | 1 | 173 | 3.3 | 5.5 | 5.3 |
| 2 | | | | High (6.5) | 1 | 191 | 3.8 | 5.3 | 3.8 |
| 3 | | | Ambient | Low (4.5) | 1 | 115 | 4.0 | 10.3 | 21.8 |
| 4 | | | | High (6.5) | 1 | 119 | 4.0 | 11.0 | 32.5 |
| 5 | | Rainwater | Humid | Low (4.5) | 1 | 165 | 3.3 | 7.3 | 12.5 |
| 6 | | | | High (6.5) | 1 | 190 | 3.8 | 8.0 | 9.8 |
| 7 | | | Ambient | Low (4.5) | 1 | 128 | 3.8 | 9.8 | 28.8 |
| 8 | | | | High (6.5) | 1 | 118 | 3.8 | 10.5 | 22.4 |
| 9 | | 50/50 blend | Humid | Low (4.5) | 1 | 182 | 3.0 | 7.5 | 9.3 |
| 10 | | | | High (6.5) | 1 | 175 | 2.5 | 6.0 | 10.0 |
| 11 | | | Ambient | Low (4.5) | 1 | 113 | 3.8 | 10.3 | 40.0 |
| 12 | | | | High (6.5) | 1 | 120 | 3.8 | 10.5 | 28.8 |
| 13 | Dry | Borehole | Humid | Low (4.5) | 1 | 163 | 4.0 | 10.0 | 5.3 |
| 14 | | | | High (6.5) | 1 | 138 | 4.0 | 10.0 | 4.8 |
| 15 | | | Ambient | Low (4.5) | 1 | 89 | 4.0 | 8.3 | 4.5 |
| 16 | | | | High (6.5) | 1 | 92 | 4.0 | 10.5 | 5.0 |
| 17 | | Rainwater | Humid | Low (4.5) | 1 | 140 | 3.8 | 9.0 | 8.0 |
| 18 | | | | High (6.5) | 1 | 144 | 4.0 | 8.3 | 5.8 |
| 19 | | | Ambient | Low (4.5) | 1 | 89 | 4.0 | 9.3 | 8.5 |
| 20 | | | | High (6.5) | 1 | 86 | 4.0 | 9.5 | 9.0 |
| 21 | | 50/50 blend | Humid | Low (4.5) | 1 | 155 | 3.8 | 10.5 | 6.8 |
| 22 | | | | High (6.5) | 1 | 179 | 3.8 | 9.0 | 4.8 |
| 23 | | | Ambient | Low (4.5) | 1 | 98 | 4.0 | 9.8 | 7.3 |
| 24 | | | | High (6.5) | 1 | 93 | 3.8 | 8.0 | 5.0 |
| | | | | s.e.d | | 15.56 | 0.1996 | 1.82 | 6.43 |
| | | | | l.s.d | | 31.32 | 0.4018 | 3.66 | 12.94 |
| | | | | F.pr | | <0.001 | <0.001 | 0.03 | <0.001 |

T= Treatment

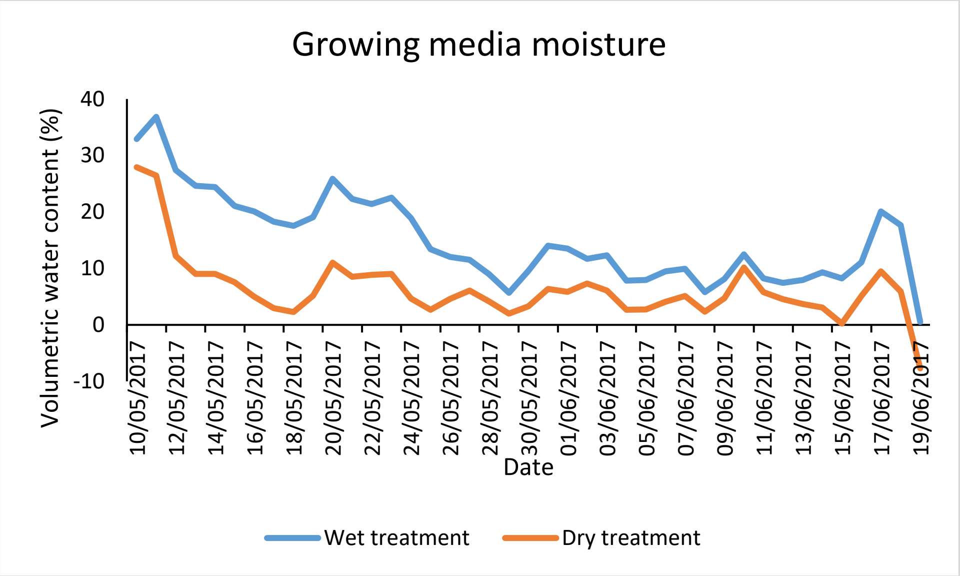
## Discussion

In general terms, plants grown under the humid environment were generally leggy, weak and pale compared to ambient treatments, and there was no single treatment where plants were deemed marketable.

**Environmental conditions** had the strongest influence, with significantly more symptoms in plants grown under ambient conditions for both parameters measured (plants per plot and proportion of plant cover with symptoms).

A closer look at the environment conditions indicates that VPD (vapour pressure deficit) was generally below 0.5 kPa in the humid environment, and approaching or above 1.0 kPa in the ambient treatments (**Appendix 1A**

Growing media moisture




**Appendix 1B**). VPD between 0.4 kPa and 1.2 kPa is generally considered an acceptable range for bedding plant production, with lower values more appropriate to plants during propagation or early growth, and higher values for late vegetative growth onwards. High VPD (>1 kPa) imparts a strong drying effect on plants, while at 0.0 kPa VPD the air is fully saturated. Plant stress can be moderated through ensuring that plants are not produced under high VPD conditions; the appropriate VPD range will vary according to plant species. For the plants in this trial, fewer symptoms developed in plants grown under generally low VPD conditions.

The 'ideal' environment appears to somewhere between the two growing environments that were tested; 'Ambient' was too dry for *Verbena* and some wetting of paths could help to reduce symptoms.

**Irrigation regime** also had a strong influence on symptom development in this trial, with significantly more plants per plot with symptoms, and a significantly greater proportion of plant cover with symptoms in plants grown under the wet regime.

**Water quality** did not have a clear influence on symptom development in this trial. It had been expected that more symptoms would develop in plants irrigated with the high EC borehole water. However, the proportion of plant cover with symptoms was significantly greater under the 50:50 blend water than borehole water, but not the rainwater (which was not significantly different to any treatment). Further, the number of plants per plot with symptoms was not significantly affected by water quality.

**Growing media pH** did not influence symptom development in this trial.

## Conclusions

Irrigation regime and environment were the strongest influences; with greater symptom development, in wet, ambient conditions. The 'ideal' environment appears to somewhere between the two growing environments that were tested; 'Ambient' was too dry for *Verbena* and some wetting of paths would help to reduce symptoms. Consideration of VPD may enable growers to determine a VPD range within which symptoms do not develop, striking a balance where plants transpire sufficiently (thereby taking up nutrients and water, and regulating their temperature) to maintain quality without symptoms developing.

Growing media moisture influences root development, with fewer roots and root hairs present in plants grown under wet conditions, limiting the ability of plants to respond during high light, temperature and VPD conditions. Care should be taken to ensure that growing media does not remain wet for long periods of time, and should be allowed to dry sufficiently before watering. Good root development will produce plants with more resilience against sharp increases in VPD and temperature stress.

## Acknowledgements

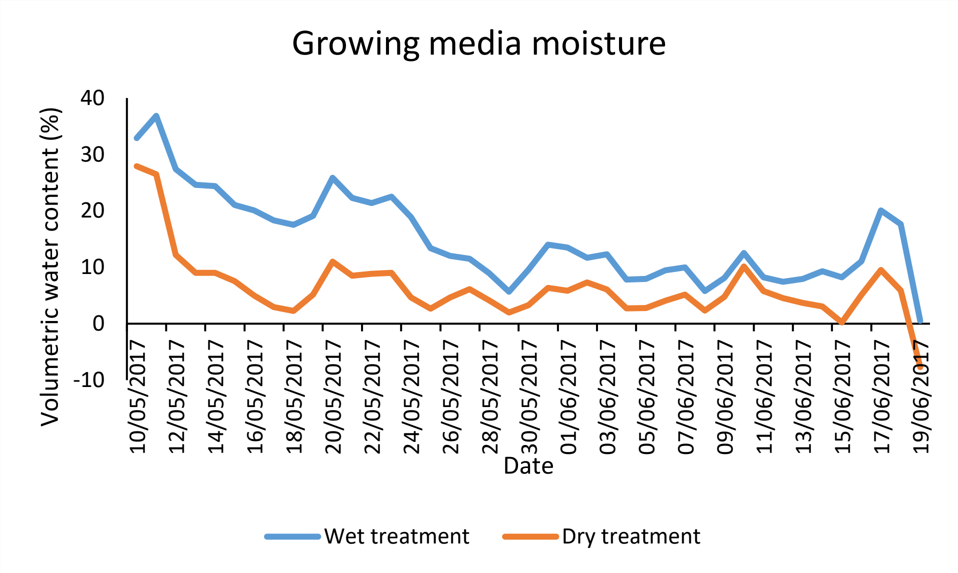
Our thanks to:

- Jamie Downes and the team at Woodlands Nursery for their support and for hosting the trial
- Bulrush Horticulture Ltd for providing the growing media
- The Scientific Support team at ADAS

- The Management Group for steering the project

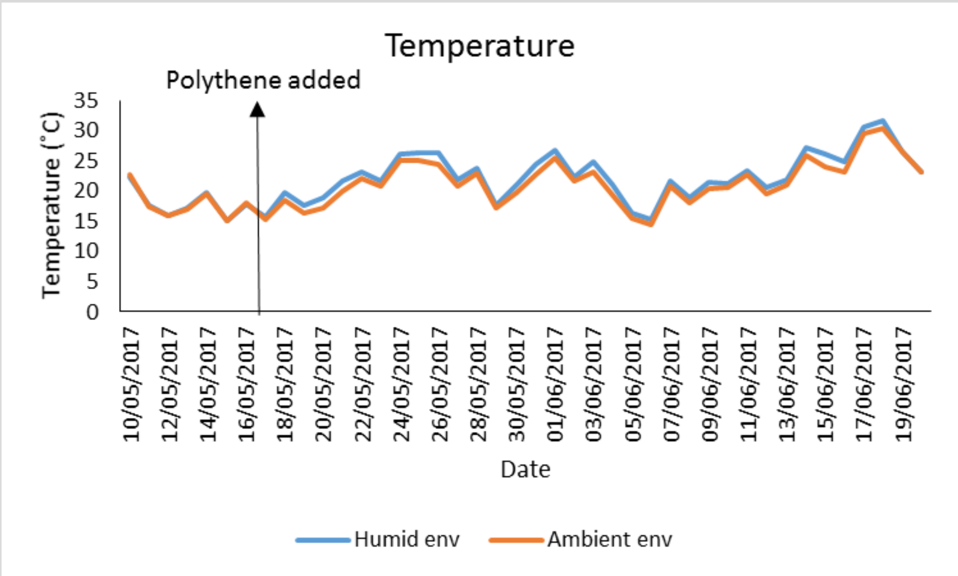
## Appendix 1A

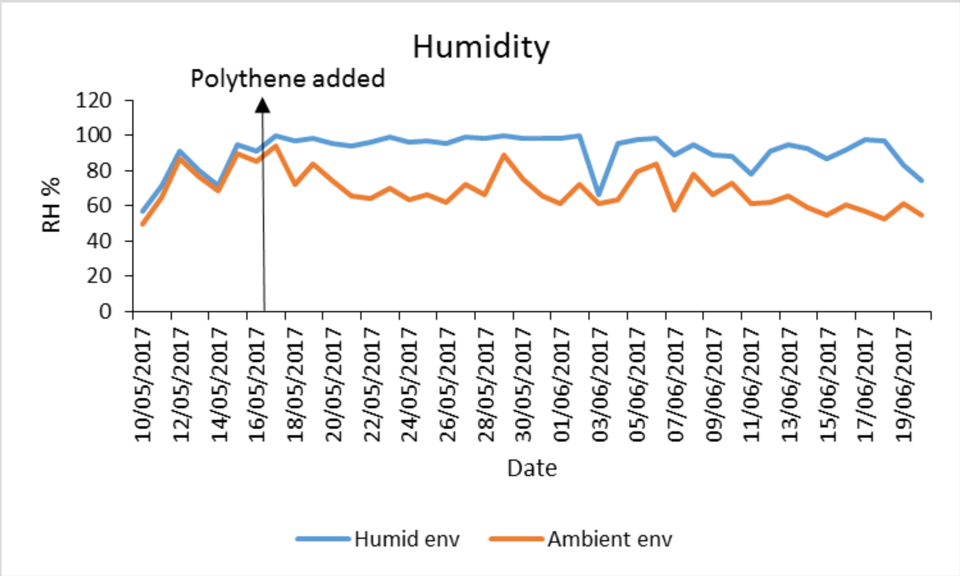
Growing media moisture

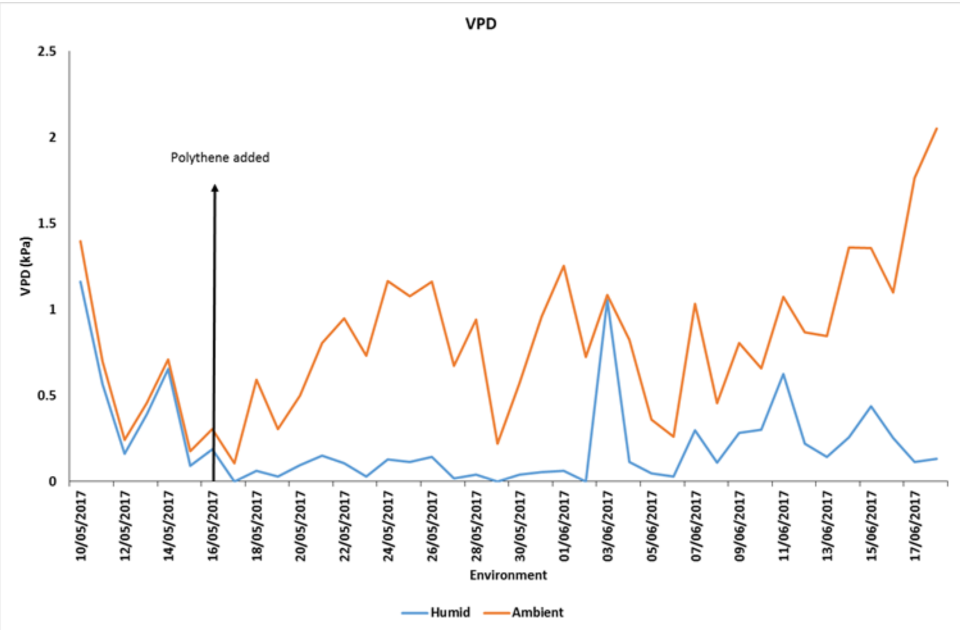



## Appendix 1B

Glasshouse daily average temperature, humidity and VPD under ambient and humid environments




Humidity
Polythene added
RH %
120
100
80
60
40
20
0
10/05/2017
12/05/2017
14/05/2017
16/05/2017
18/05/2017
20/05/2017
22/05/2017
24/05/2017
26/05/2017
28/05/2017
30/05/2017
01/06/2017
03/06/2017
05/06/2017
07/06/2017
09/06/2017
11/06/2017
13/06/2017
15/06/2017
17/06/2017
19/06/2017
Date
Humid env
Ambient env


VPD
Polythene added
VPD (kPa)
2.5
2
1.5
1
0.5
0
10/05/2017
12/05/2017
14/05/2017
16/05/2017
18/05/2017
20/05/2017
22/05/2017
24/05/2017
26/05/2017
28/05/2017
30/05/2017
01/06/2017
03/06/2017
05/06/2017
07/06/2017
09/06/2017
11/06/2017
13/06/2017
15/06/2017
17/06/2017
Environment
Humid
Ambient

## Appendix 2A

Water analyses

| Treatment | pH | Conductivity | Nitrate-N | $SO_4$ | B | Cu | Mn | Zn | Fe | Cl | P | K | Mg | Ca | Na | Alkalinity as $HCO_3$ | Carbonate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | uS/cm | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| Borehole | 7.2 | 2264.16 | <0.1 | 1707.5 | 0.43 | <0.01 | 0.18 | 0.04 | 0.36 | 13.6 | <0.1 | 12.2 | 86.89 | 649 | 35.8 | 263 | <10 |
| 50:50 blend | 7.7 | 875.47 | 2.2 | 406.1 | 0.13 | <0.01 | <0.01 | 0.05 | 0.1 | 28.4 | 0.4 | 5.3 | 27.32 | 176.2 | 24.2 | 143 | <10 |
| Rainwater | 5.7 | 11.05 | 0.3 | 1.1 | <0.01 | 0.06 | <0.01 | 0.12 | 0.06 | 0.5 | 0.1 | <0.3 | 0.22 | 1.5 | 0.4 | <10 | <10 |

## Appendix 2B

Growing media analyses

| Growing media analysis | | pH | Cond. | Den. | Dry matter | Dry den. | $NH_4$-N | $NO^3$-N | Total N | Cl | P | K | Mg | Cl | Na | $SO_4$ | B | Cu | Mn | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | uS/cm | $Kg/m^3$ | % | $kg/m^3$ | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| Unused growing media | Low pH | 4.1 | 301 | 338 | 34.7 | 117.3 | 77.1 | 88.4 | 165.5 | 13.3 | 52.3 | 111.3 | 29.5 | 22.8 | 27.4 | 220.7 | 0.19 | 0.01 | 0.27 | 0.08 | 0.92 |
| Unused growing media | High pH | 5.5 | 312 | 355 | 34.9 | 123.9 | 72.2 | 99.2 | 171.3 | 16.7 | 45.0 | 116.0 | 29.9 | 46.7 | 28.2 | 226.9 | 0.11 | 0.03 | 0.17 | 0.11 | 1.06 |
| W, BH, AMB, low pH | T3 NS | 3.9 | 957 | 495 | 22.9 | 113.4 | 14.5 | <0.6 | 15.1 | 13.0 | 8.9 | 31.9 | 225.4 | 713.2 | 83.2 | 3064.6 | 0.45 | 0.02 | 1.75 | 0.37 | 0.56 |
| W, BH, AMB, low pH | T3 S | 3.9 | 758 | 501 | 21.8 | 109.2 | 14.5 | 0.7 | 15.2 | 10.2 | 5.3 | 23.6 | 171.2 | 505.3 | 66.5 | 2378.9 | 0.40 | 0.02 | 1.29 | 0.49 | 0.48 |
| W, BH, AMB, high pH | T4 NS | 5.8 | 315 | 434 | 27.0 | 117.2 | 11.1 | <0.6 | 11.5 | 7.4 | 2.1 | 5.8 | 56.6 | 180.2 | 30.9 | 848.4 | 0.29 | 0.01 | 0.08 | 0.17 | 0.25 |
| W, BH, AMB, high pH | T4 S | 5.4 | 806 | 445 | 23.5 | 104.6 | 9.3 | <0.6 | 9.4 | 6.7 | 2.6 | 4.5 | 187.3 | 637.9 | 72.8 | 2694.0 | 0.29 | 0.02 | 0.28 | 0.27 | 0.24 |
| W, RW, AMB, low pH | T7 NS | 4.2 | 160 | 476 | 23.6 | 112.3 | 13.2 | 30 | 43.2 | 32.7 | 3.4 | 16.3 | 20.8 | 37.1 | 41.2 | 196.4 | 0.09 | 0.01 | 0.25 | 0.12 | 0.40 |
| W, RW, AMB, low pH | T7 S | 4.0 | 135 | 494 | 21.8 | 107.7 | 10.5 | 0.7 | 11.2 | 16.7 | 4.6 | 20.7 | 17.6 | 18.4 | 37.1 | 262.2 | 0.12 | 0.02 | 0.16 | 0.15 | 0.78 |
| W, RW, AMB, high pH | T8 NS | 5.5 | 147 | 379 | 29.3 | 111.0 | 17.5 | 2.1 | 19.6 | 16.5 | 3.4 | 12.8 | 23.9 | 50.2 | 41.3 | 330.4 | <0.05 | 0.01 | 0.06 | 0.3 | 0.46 |
| W, RW, AMB, high pH | T8 S | 5.6 | 102 | 494 | 24.7 | 122.0 | 14.6 | 0.6 | 15.3 | 14.1 | 3.4 | 6.0 | 15.0 | 28.1 | 29.4 | 208.4 | <0.05 | 0.02 | <0.01 | 0.05 | 0.45 |
| W, 50:50, humid, low pH | T9 NS | 4.2 | 182 | 567 | 20.4 | 115.7 | 30.5 | 4.7 | 35.3 | 17.9 | 8.8 | 34.2 | 15.8 | 23.9 | 30.9 | 331.9 | 0.16 | 0.01 | 0.18 | 0.22 | 0.5 |
| W, 50:50, AMB, low pH | T11 NS | 3.9 | 224 | 476 | 22.8 | 108.5 | 12.7 | 2.2 | 14.9 | 13.7 | 5.2 | 25.7 | 42.2 | 48.6 | 45.1 | 488.0 | 0.16 | 0.02 | 0.39 | 0.23 | 0.64 |
| W, 50:50, AMB, low pH | T11 S | 4.0 | 183 | 450 | 23.7 | 106.7 | 22.9 | 5.3 | 28.1 | 15.9 | 6.3 | 22.7 | 29.4 | 33.5 | 42.4 | 376.7 | 0.14 | 0.01 | 0.27 | 0.08 | 0.46 |
| W, 50:50, AMB, high pH | T12 NS | 5.4 | 194 | 374 | 26.8 | 100.2 | 14.8 | 0.6 | 15.4 | 10.2 | 3.2 | 4.2 | 41.4 | 78.9 | 38.7 | 496.4 | 0.05 | 0.03 | 0.13 | 0.07 | 0.51 |
| W, 50:50, AMB, high pH | T12 S | 5.5 | 341 | 400 | 28.2 | 112.8 | 17.9 | 18.7 | 36.6 | 24.4 | 5.1 | 7.4 | 80.7 | 161.2 | 64.3 | 857.6 | 0.07 | 0.03 | 0.25 | 0.13 | 0.45 |
| D, 50:50, AMB, low pH | T23 NS | 4.0 | 221 | 462 | 24.5 | 113.2 | 17.4 | <0.6 | 17.9 | 12.7 | 3.3 | 19.8 | 43.2 | 59.2 | 37.7 | 502.5 | 0.13 | 0.02 | 0.36 | 0.11 | 0.79 |
| D, 50:50, AMB, low pH | T23 S | 3.9 | 208 | 477 | 22.7 | 108.3 | 18.1 | 0.7 | 18.8 | 10.4 | 2.8 | 11.5 | 41.1 | 54.2 | 35.6 | 469.5 | 0.13 | 0.02 | 0.36 | 0.1 | 0.37 |

Unused and used. W = wet; BH = borehole; AMB = ambient; S = symptoms; NS = no symptoms

## Appendix 2C

Plant tissue analyses

| Treatment | | Total N DUMAS % w/w | P mg/kg | K mg/kg | Ca mg/kg | Mg mg/kg | S mg/kg | Mn mg/kg | Cu mg/kg | Zn mg/kg | Fe mg/kg | B mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial tissue sample | NS | 3.580 | 5100 | 32300 | 25500 | 5500 | 4406 | 121 | 12.4 | 58.5 | 157 | 24.0 |
| W, BH, AMB, low pH | T3 NS | 2.775 | 6306 | 28295 | 10618 | 8029 | 14040 | 101 | 2.7 | 35.0 | 115 | 58.4 |
| W, BH, AMB, low pH | T3 S | 2.482 | 7260 | 32052 | 12429 | 8506 | 15773 | 145 | 5.1 | 36.9 | 434 | 74.8 |
| W, BH, AMB, high pH | T4 NS | 2.999 | 4651 | 33777 | 22298 | 10023 | 8801 | 214 | 2.0 | 38.0 | 140 | 43.0 |
| W, BH, AMB, high pH | T4 S | 2.339 | 5777 | 26054 | 28038 | 13619 | 8886 | 291 | 2.4 | 37.7 | 164 | 42.2 |
| W, RW, AMB, low pH | T7 NS | 2.931 | 7076 | 28551 | 11566 | 5535 | 5243 | 130 | 1.5 | 28.9 | 93 | 31.6 |
| W, RW, AMB, low pH | T7 S | 3.049 | 10651 | 25246 | 9779 | 5913 | 5253 | 114 | 2.3 | 27.1 | 120 | 36.5 |
| W, RW, AMB, high pH | T8 NS | 2.977 | 6143 | 33444 | 16947 | 6526 | 4446 | 133 | 1.9 | 31.6 | 119 | 32.0 |
| W, RW, AMB, high pH | T8 S | 2.475 | 7161 | 26570 | 21649 | 8096 | 3724 | 163 | 2.5 | 34.2 | 153 | 31.0 |
| W, 50:50, humid, low pH | T9 NS | 3.412 | 5658 | 29483 | 25232 | 11473 | 6014 | 220 | 4.1 | 52.5 | 257 | 27.9 |
| W, 50:50, AMB, low pH | T11 NS | 2.516 | 7002 | 23715 | 7828 | 5806 | 9773 | 91 | 2.1 | 31.6 | 86 | 32.6 |
| W, 50:50, AMB, low pH | T11 S | 3.225 | 9494 | 28661 | 9824 | 6579 | 8295 | 116 | 2.4 | 28.6 | 113 | 39.9 |
| W, 50:50, AMB, high pH | T12 NS | 2.102 | 3566 | 25861 | 16793 | 8167 | 4806 | 169 | 4.1 | 38.9 | 1358 | 32.3 |
| W, 50:50, AMB, high pH | T12 S | 2.294 | 5855 | 25100 | 23360 | 9358 | 4387 | 192 | 3.4 | 36.3 | 572 | 30.3 |
| D, 50:50, AMB, low pH | T23 NS | 2.778 | 8391 | 30905 | 9141 | 6732 | 12583 | 94 | 2.5 | 33.9 | 135 | 39.1 |
| D, 50:50, AMB, low pH | T23 S | 2.393 | 7052 | 24680 | 7702 | 5480 | 8686 | 79 | 1.3 | 24.0 | 108 | 39.2 |

Unused and used. W = wet; BH = borehole; AMB = ambient; S = symptoms; NS = no symptoms

## Appendix 3

Treatment images

| | | |
|---|---|---|
| <br>**T1. Wet, borehole, humid, low pH (4.5)** | <br>**T2. Wet, borehole, humid, high pH (6.5)** | <br>**T3. Wet, borehole, ambient, low pH (4.5)** |
| <br>**T4. Wet, borehole, ambient, high pH (6.5)** | <br>**T5. Wet, rainwater, humid, low pH (4.5)** | <br>**T6. Wet, rainwater, humid, high pH (6.5)** |
| <br>**T7. Wet, rainwater, ambient, low pH (4.5)** | <br>**T8. Wet, rainwater, ambient, high pH (6.5)** | <br>**T9. Wet, 50:50 blend, humid, low pH (4.5)** |
| <br>**T10. Wet, 50:50 blend, humid, high pH (6.5)** | <br>**T11. Wet, 50/50 blend, ambient, low pH (4.5)** | <br>**T12. Wet, 50/50 blend, ambient, high pH (6.5)** |

**T13. Dry, borehole, humid, low pH (4.5)**

**T14. Dry, borehole, humid, high pH (6.5)**

**T15. Dry, borehole, ambient, low pH (4.5)**

**T16. Dry, borehole, ambient, high pH (6.5)**

**T17. Dry, rainwater, humid, low pH (4.5)**

**T18. Dry, rainwater, humid, high pH (6.5)**

**T19. Dry, rainwater, ambient, low pH (4.5)**

**T20. Dry, rainwater, ambient, high pH (6.5)**

**T21. Dry, 50:50 blend, humid, low pH (4.5)**

**T22. Dry, 50:50 blend, humid, high pH (6.5)**

**T23. Dry, 50/50 blend, ambient, low pH (4.5)**

**T24. Dry, 50/50 blend, ambient, high pH (6.5)**