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Signed on behalf of Warwick HRI:

Signature:…………………………………………… ***Date***: ……………………………
Name:

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

CONTENTS

GROWER SUMMARY

Headline

The pH alone has little effect on adventitious rooting of cuttings in hardy nursery stock.

Background and expected deliverables

Rooting HNS species can be difficult with an estimated 25% failure rate for the 200 million cuttings rooted annually (Harrison-Murray, 2003). Previous studies have examined how the aerial environment may be manipulated to minimise stress whilst roots develop. Work has also looked at how the balance of air and water within the growing medium influences rooting (Harrison-Murray, 2003). Whilst it is widely accepted than adventitious roots are initiated by plant hormones, chemical factors within the root environment such as pH and concentration of nutrients can also influence the rooting process (Anderson, 1986). Anecdotal evidence from the industry also suggested that the influence of pH on rooting would warrant further investigation.

Methods were developed to examine the responses of unrooted cuttings to pH whilst minimising the complication of interaction with nutrition or changes in other parameters that can result in altering the pH of more conventional substrates used for rooting. Whilst root development was successful in pilot studies, rooting in the initial main experiments was slower than expected and there was little consistent difference due to pH within the range 4 to 8. Experimental systems were modified to improve speed of rooting and therefore confidence in results. Easily rooted species, such as rosemary and fuchsia, rooted well in experimental systems with no differences between the five pH levels tested. Slower rooting species, such as heathers, took longer to root than expected from commercial experience, with rooting progress appearing to stall in some for several weeks in some cases, once cuttings had developed to the root initial stage. When treatments were considered ready for final scoring, again there was little difference between 4 and 8. Final year experiments were therefore designed to encourage faster rooting by including variables suspected to be slowing the rooting in previous experiments; these included substrate type (particularly aeration), nutrient availability and stage of rooting in order to have confidence in the lack of difference relating to pH level seen in earlier work. Where possible, pH range was also extended beyond the original range to pH 2 to 10, to determine if a response could be generated with more extreme treatments.

Summary of the project and main conclusions

Experiments in year 3 examined seven species with the two heather species repeated in October and July (summarised in Table 1 below).

Table 1 Summary of species examined and striking date of each

Species / cultivar	Date struck	Days from striking to assessment
October 2007 experiments		
Calluna vulgaris 'Allegro'	10-16/10/2007	49-55 (up to 107 in perlite)
Erica carnea 'Pink Spangles'	16/10/2007	100
May 2008 experiments		
Clematis Dr. Ruppel	14/05/2008	63
Vaccinium corymbosum 'Bluecrop'	15/05/2008	60-61
Rose Red bells	15-16/05/2008	27-28
July 2008 experiments		
Calluna vulgaris 'Allegro'	25/07/2008	35
Vaccinium oxycoccos	25/07/2008	39-41
Rhododendron 'Chikor'	25/07/2008	59-61
Erica carnea 'Pink Spangles'	25/07/2008	54

All experiments examined:

- pH within the range 2 to10, at intervals of 2 pH units,

- nutrition at either 10 mg/l N or 70 mg/l N with other nutrients in proportion to N (where 10 mg/l N represents a low nutrition and 70 mg/l N represents standard nutrition derived from the concentration of N available using a base feed of 13:11:23 PG mix at a rate of 0.5 kg/m^3),

- substrate type (Sphagnum peat/perlite mix or Cornish grit),

- the use of lime to raise pH in a standard peat/perlite mix.

Initial experiments in October also examined how stage of rooting influences response to pH by transferring partially rooted cuttings into treatments once root initials had become established; and included a third substrate (perlite) to assess if aeration was adequate in the peat/perlite and grit substrates used.

The response to treatments is summarised in Table 2. Main experiments with Clematis were too severely infected with *Botrytis* for results to be included in this summary.

Table 2 Summary of species response to treatments

Species	Substrate	pH effects	Feed preference	Substrate preference
Rhododendron	peat/perlite	pH 2 poorest followed by pH 10. No differences pH 4-8	10 mg/l N	Peat/perlite
	grit	pH 4 best, pH 2 poorest, no differences pH 6-10	10 mg/l N at pH 4	
Cranberry	peat/perlite	pH 2 poorest, no differences pH 4-10	None	Peat/perlite at pH 8
	grit	ph 4 & 6 best, pH 2 poorest, pH 8-10 intermediate	10 mg/l N	Grit at pH 6
Rose	peat/perlite	pH 2 poorest, no differences pH 4-10	None	No differences
	grit	pH 2 poorest, no differences pH 4-10	None	
Calluna vulgaris	peat/perlite	pH 2 poorest, followed by pH 10, no differences pH 4-8	10 mg/l N	Peat/perlite
	grit	No differences, all poor	None	
Erica carnea	peat/perlite	pH 2 poorest followed by pH 10. No differences pH 4-8	10 mg/l N	Peat/perlite
	grit	pH 4 best pH 2 poorest	10 mg/l N	
Blueberry	peat/perlite	pH 2 poorest, no differences pH 4 to 10	10 mg/l N	Peat/perlite
	grit	No differences, all poor	None, all poor	

Irrigation with the pH 2 nutrient solution consistently restricted rooting and in many cases caused cuttings to die back. Higher pH (8-10) also reduced rooting of some of the species tested (*Rhododendron, C.vulgaris and E.carnea*), however *Rhododendron* and *E.carnea* produced a surprising amount of root at pH 10 given the ericaceous nature of these species. There was better rooting within the pH 4-6 range for Cranberry, *E.carnea* and *Rhododendron* rooted in grit but in peat/perlite these species along with the others tested had comparable rooting with the pH range 4-8.

In initial experiments with *C.vulgaris* and *E.carnea* in October 2007, some cuttings were struck in a standard commercial substrate and then transferred to pH treatments once partially rooted. These treatments demonstrated that where a response to pH was found, it occurred for both the early and later stages of adventitious rooting.

Whilst the pH 2 treatment significantly reduced rooting in all experiments, this treatment was also associated with high substrate conductivity e.g. peat/perlite substrates had a final conductivity of 239µS/cm (at 20°C) after treatment with the pH 2 10 mg/l N solution, due to a general increase in nutrient ion concentration (see Table 3 below) probably as a result of components of the substrate being dissolved by the low pH solution. To put this increase in conductivity into context, the highest concentration feed treatment, with a conductivity of around 82 µS/cm (at 20°C) also restricted rooting. The restriction on rooting at pH 2 may therefore have been associated with the increase in conductivity as well as the low pH level itself. High conductivity would be expected to create a drought type stress due to a restriction of the movement of water into the cutting by osmosis and may also result in the build up of toxic concentrations of elements such as sodium (Na) in shoot tissue (depending on the nature of the increase in conductivity).

Table 3 Summary of nutrient composition and conductivity at a range of target pH values

Target pH	Conductivity (µS/cm 20°C)	NO_3-N (mg/l)	NH_4-N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)	Na (mg/l)	S (mg/l)
2	239.40	5.19	3.29	13.16	26.54	16.90	2.08	123.30	118.32
4	51.05	4.31	0.72	7.82	2.07	0.79	1.47	83.85	23.98
6	54.20	6.56	0.15	8.14	2.87	1.30	2.28	92.27	21.36
8	40.92	1.58	0.00	5.21	1.19	0.45	1.54	72.37	16.08
10	41.64	1.02	0.00	4.58	1.60	0.55	1.25	73.05	12.96

Mineral analysis data also suggests that peat/perlite was better buffered against change in pH at higher levels than the grit, which may explain the different responses to higher pH. Peat/perlite generally produced either equivalent or better rooting than grit but, because of the differences in buffering, was less suited to assessing the direct effects of pH on rooting. Given the results from the grit and peat/perlite systems, both substrates were used in subsequent experiments in May and July 2008. Perlite was generally the poorest of the three substrates tested using the irrigation system developed, and was therefore only included in the initial October 2007 experiments.

Whilst some response to the pH treatments has been demonstrated in year 3, differences were smaller than expected, which also reflects the results generated in years 1 and 2 of this project. The greatest reaction occurred to the pH 2 treatment. Mineral analysis indicates that this may at least in part be associated with increased conductivity.

Parallel, unreplicated treatments examined how the species tested might respond to changing pH in an unfertilised peat/perlite substrate when lime is used. A more predictable response was observed to treatments in these experiments (Table 4). *C.vulgaris* and *E.carnea* preferred to root in the unlimed peat/perlite mix. *Rhododendron*, Blueberry and *Clematis* preferred lower rates of lime (0 to 3.25 g/l or pH 4.6 to 6.0). Cranberry was less influenced by rate of lime, performing best at 0-20 g/l (pH 4.6 to 6.7) and Rose preferred a higher rate of lime (10 g/l or pH 6.2). As would be expected however, concentration of ions such as Ca and Mg also increased as rate of lime increased as did a wide range of mineral elements. In this case, the change in mineral element concentration had less impact on conductivity which remained within the range 42-62µS/cm (at 20°C), but clearly the change in pH in these treatments was accompanied by other changes in chemical composition which may have influenced rooting.

Table 4 Optimum species response in limed peat/perlite at varying pH values

Species	**Substrate**	**Lime effects**
Rhododendron	limed peat/perlite	Lime at 0 to 3.5 g/l (i.e. pH 4.6 to 6.0) best.
Cranberry	limed peat/perlite	Lime at 0 - 20 g/l (i.e. pH 4.6 to 6.7) best
Rose	limed peat/perlite	Lime at 10 g/l (pH 6.2) best
Calluna vulgaris	limed peat/perlite	No lime (pH 4.6) best with decline in rooting in all limed treatments
Erica carnea	limed peat/perlite	No lime (pH 4.6) best
Blueberry	limed peat/perlite	Lime at 0 - 3.25 g/l (pH 4.6 to 6.0) better than at 10 - 20 g/l (pH 6.2 to 6.5)
Clematis	limed peat/perlite	Lime at 0 to 10 g/l (pH 4.6 to 6.0) better than at 20 g/l (pH 6.5)

In summary, adventitious rooting was less responsive to pH treatments than was expected when experiments separated the direct effects of pH from the changes in mineral ion concentrations that are associated with pH in conventional systems. This corresponds to results of experiments carried out in years 1 and 2 of the project where a total of 11 species (including the two heather species assessed in year 3) have been assessed for response to pH. In year 2 experiments in particular, no significant differences were found within the range pH 4 to 8. Species with some response to pH treatments in year 1 included *Ceanothus* (preferring pH 7) and Rosemary (preferring pH 4-6). *Fuchsia* cv Dollar Princess had no significant response to pH but cv Beacon Rosa preferred pH 4-6.

Adventitious rooting of all species tested in year 3 was either poorer where a higher nutrient concentration feed was used, or in the case of Rose, was not improved by increasing nutrient concentration from 10 mg/l N to 70 mg/l N (with other elements supplied in proportion to N). Since cuttings are commonly struck in smaller propagation modules prior to transplant into liners or larger containers, there may be some advantage to this low nutrient requirement. Cuttings can be struck in a low nutrient concentration medium without restricting initial root development. Once rooted, shoot development of cuttings would be expected to be restricted when nutrient availability is low. This means the rooted cuttings will be automatically held back until more vigorous growth is required, which can be triggered by applying liquid feed or by potting up into a fertilised substrate according to potting and marketing schedules.

Financial benefits

The results suggest that for adventitious rooting alone, pH may have little impact on rooting providing nutrient status is suitable. For a range of both vigorous and slow rooting species, better rooting resulted from lower nutrition. This indicates potential for a simple strategy of using low nutrient status rooting media with pH within the range 4-6 for a range of species rather than the use of specialised media for each species/family grown, which would be expected to have financial and management benefits. Such a system would require the flexibility to boost nutrition to promote shoot growth once cuttings are rooted which could be achieved via liquid feeding or potting on. Where plants need to be held however, maintenance in low nutrient status media would help to minimise the trimming that is associated with more vigorous growth.

Action points for growers

The direct effects of pH alone on adventitious rooting have been small overall but raising pH of a peat based substrate with lime produced more predictable responses (e.g. ericaceous species preferring lower pH) due to the impact of pH on substrate nutrient status. For most species tested in this project, low lime was best suited to developing adventitious rooting.

- Maintain low nutrient levels in media for adventitious rooting

- Available N at 10 mg/l (with other elements in proportion) applied via liquid feeding was adequate for a range of species whilst increasing N to 70 mg/l (with equivalent N concentration to 13:11:23 PG mix at 0.5 kg/m3) was detrimental.

- This is equivalent to conductivity levels in the substrate of around 240µS/cm (at 20°C) for the high N treatment and 40-50 µS/cm (at 20°C) for the low N treatment from the use of liquid feed with conductivities of around 2500µS/cm (at 20°C) and 600µS/cm (at 20°C) respectively.

- Where in use, regularly check acid dosing systems, since sustained over-dosing has the potential not only to lower pH but also to raise substrate conductivity.

- This is apparently due to both the accumulation of the chemicals originating from the acid (e.g. sulphates in the case of the sulphuric acid used in these experiments), and also from components of the medium being dissolved in the acidic conditions.

- This build up of conductivity can create osmotic (drought) stress and possibly also result in the accumulation of toxic concentrations of ions in plant tissues leading to cutting death.

SCIENCE SECTION

INTRODUCTION

Two main issues were addressed in this project. The first of these is the problems encountered with rooting HNS cuttings with an estimated 25% failure rate for the 200 million cuttings rooted annually (Harrison-Murray, 2003). Problems with plant uniformity are also closely associated with rooting performance of cuttings. Work has examined how factors of the aerial environment such as RH, temperature and light influence rooting (Anon, 1999). The effects of media type on the balance of air and water in the growing medium has also been investigated for HNS species (Harrison-Murray, 2003). Reports in the scientific literature suggest how the chemical environment and specifically pH may influence rooting of explants in vitro (e.g. Pierick et al., 1975, Rahman et al., 1992) with preferred levels determined by species. Anecdotal evidence from a commercial heather grower suggests that manipulation of pH in conventional growing systems may encourage rooting of heathers and may merit investigation in other HNS species.

The second issue addresses the position within the industry with regards to control over the root environment. HNS production in the UK relies heavily on the use of CRFs for nutrition which provides a manageable solution to the wide range of species and growth stages likely to be encountered on one nursery. However the benefits of greater control over the root environment have been clearly demonstrated in other sectors of the industry e.g. the significant increases in yield achieved by adopting hydroponics for tomato crops. Specialised HNS nurseries may similarly benefit from the increased control over the root environment that might be achieved using liquid feeding systems. Rooting cuttings is one production phase in which the benefits of this technology could be investigated.

In year 1 (HNS 138 annual report 2006), pilot studies were carried out to devise a suitable experimental system for testing responses of unrooted cuttings to pH whilst minimising interactions with nutrient availability. These studies led to the development of a sand-based system for supporting cuttings with pH treatments applied via a low concentration nutrient solution applied as recirculating ebb and flood irrigation. In experiments with four species of heather, *Ceanothus*, *Fuchsia* and Rosemary struck between April and May, response to a wide pH range (pH 4 to 8) was either small or not significant; however rooting was often slower than expected and cuttings of some species died back before rooting. Extreme high temperatures in 2006 may have contributed to the death of cuttings and changes in system design were implemented in order to progress with further work in 2006/07.

A further 9 HNS species were tested in the modified sand-based ebb and flood system during year 2 (HNS 138 annual report 2007). Overall response to pH over a wide range (i.e. pH 4 to 8) continued to be smaller than expected. Rooting time was longer than expected for the heather species tested and detailed interim inspections suggested that initial rooting stalled when rooting failed to progress beyond the development of root initials over a period of weeks. Hence whilst results apparently confirmed those produced in year 1, concern remained that, because rooting was slower than expected, factors other than the pH treatments applied were limiting rooting and hence potentially also limiting response to pH.

Experiments in year 3 were therefore designed to investigate several factors that could have limited rooting in experimental systems used in year 1 and 2 of the project. These included assessing substrate type using a more open perlite based system as well as a more conventional peat/perlite substrate alongside Cornish grit which formed a more open sand-type substrate in place of the sand used in years 1 & 2. Mineral nutrition was also assessed by including the nutrient concentration used in previous years and a higher concentration supplemented with micronutrients to determine if rooting progress has been limited by low nutrient status in previous experiments. Finally changes in sensitivity with stage of progression towards rooting were examined to determine if the lack of response seen was due to changes in pH sensitivity in cuttings during adventitious rooting.

MATERIALS AND METHODS

System design and maintenance

A series of experiments were carried out in October 2007, May and July 2008. Each replicate system consisted of the appropriate substrate contained in an independent trough irrigated using seep hose via a pump on a timer set to irrigate for 2 minutes at 12 hour intervals. Excess nutrient solution was run to waste. Troughs were covered with sealed curved perspex covers to maintain high humidity.

The glasshouse compartment was set to heat at 7°C and vent at 18°C with forced ventilation (via fans) triggered at 20°C. Fixed shade screens were used over hoops approximately 50cm above the troughs and were supplemented with moveable shade screens in the compartment roof which were set to close at external light intensities above 500 W/m².

Substrate treatments

Three growing media were used, perlite (P25 grade with particle size 2 to 3.5mm), mixed sphagnum peat and perlite (50:50) and Cornish grit. Grit and perlite were treated with a pH adjusted solution in order to pre-condition them to the relevant pH. Sulphuric acid was used to decrease solution pH and sodium hydroxide was used to increase it. After soaking with agitation for 48 hours, the drained grit or perlite was used to fill the troughs. The peat/perlite was prepared by first sieving the peat through a 4mm mesh and then mixing it 50:50 by volume with perlite (P25 grade with particle size 2 to 3.5mm) before filling troughs. These troughs were wet up using the appropriate pH adjusted nutrient solution prior to striking cuttings.

pH adjusted nutrient solutions

Main treatments were supplied with two nutrient solution concentrations. The nutrient solution from original experiments, designed to represent low level nutrition only, supplied N at 10 mg/l with other major nutrients supplied in suitable proportions to this as used in general purpose liquid feeds (i.e. P at 3 mg/l, K at 15 mg/l, Ca at 15 mg/l and Mg at 3 mg/l). The higher concentration nutrient solution was designed to assess if lack of nutrient was delaying rooting in previous experiments and was therefore designed to have higher macronutrient concentration and also to be supplemented with micronutrients. The higher concentration feed solution used the same stock recipe as the lower concentration but was less dilute in order to give N at 70 mg/l (which represents the concentration of N available using a base feed of 13:11:23 PG mix at a rate of 0.5 kg/m^3 of peat), with the remaining nutrients in the same proportions to N as in the 10 mg/l N feed. Micronutrients were supplied using BMX with typical concentrations of Fe at 0.9 mg./l, B at 0.08 mg/l, Cu at 0.50 mg/l, Zn at 0.07 mg/l and Mn 0.45 mg/l in the dilute feed.

The two concentrations of nutrient solution were adjusted with either sulphuric acid or sodium hydroxide to achieve target pHs of 4, 6 or 8, spanning the range used in year 1 and 2 experiments. These treatments were applied to all substrates.

The pH range tested was further extended to pH 2 and 10 in combination with the 10 mg/l N feed applied to the grit and perlite substrates.

Solution pH was checked three times a week and adjusted whenever the pH drifted more than 0.2 units away from the target level. Testing was carried out by stirring the reservoir and measuring pH using a hand held meter with further stirring and testing where acid or alkali was needed to adjust pH. Tanks were topped up with fresh solution as required.

Lime treatments

Unreplicated observational treatments examined changing the pH of a 50:50 sphagnum peat and perlite mix with dolomitic lime. Rates of lime used expanded as experiments progressed, starting with 0, 3 and 8.25 g/l in October 2007, extending to 0, 3.25, 10 and 20 g/l in May 2008 and 0, 3.25, 10, 20, 40, 80 and 120 g/l in July 2008.

Plant material

Cuttings prepared for striking were sourced from commercial suppliers with selection/grading to minimise variability in the initial plant material. Species tested in these experiments are summarised in table 1 along with growing medium, pH or lime treatment and date of striking.

Cuttings were re-cut prior to striking to standardise length. Ten cuttings were struck in each of the treatments of the main trial so that approximately 50% of the length of the stem was beneath the surface of the substrate.

Table 1. Summary of species tested in year 3 experiments

Species / cultivar	Date struck	Days from striking to assessment
Calluna vulgaris 'Allegro'	10-16/10/2007	49-55 (up to 107 in perlite)
Erica carnea 'Pink Spangles'	16/10/2007	100
Clematis Dr. Ruppel	14/05/2008	63
Vaccinium corymbosum 'Bluecrop'	15/05/2008	60-61
Rose Red bells	15-16/05/2008	27-28
Calluna vulgaris 'Allegro'	25/07/2008	35
Vaccinium oxycoccos	25/07/2008	39-41
*Rhododendron '*Chikor'	25/07/2008	59-61
Erica carnea 'Pink Spangles'	25/07/2008	54

October 2007 treatments

Initial experiments in year 3 focussed on two heather species, *Erica carnea* 'Pink Spangles' and *Calluna Vulgaris* 'Allegro' with a wide range of treatments including:

- pH: 2, 4, 6, 8 or 10
- Substrate: grit, peat/perlite, perlite
- Nutrition: 10 mg/l N, 70 mg/l N (with other elements in proportion to N and the higher N feed supplemented with micronutrients)

- Rooting stage: direct struck or transferred after initial rooting in a standard commercial substrate

For cuttings that were transferred, the aim was to reach rooting stage 3 (i.e. root initials starting to appear) before transfer. In practise some cuttings had progressed beyond the very early stages of root initial development prior to transfer because of variability between cuttings and the need to produce sufficient numbers for the transfers to take place. Transferred cuttings were rooted in the initial peat/perlite medium for 29 days prior to being transferred into the main experimental treatments.

Unreplicated observation treatments compared response to pH in the main experimental systems (where the aim was to keep nutrition constant), with response to pH in a peat/perlite substrate amended with dolomitic limestone. Lime was added to the substrate at 0, 3 or 8.25 g/l.

Given the high number of treatments, troughs were not replicated in this experiment. To allow some limited statistical comparison the ten cuttings were struck into each treatment were analysed as ten replicates.

May and July 2008 treatments

Later experiments focussed on the peat/perlite and grit substrates since they had produced the best rooting in initial work in year 3. Two nutrient levels were compared in combination with pH in the range 2-10 for the 10 mg/l N treatment and 4-8 for the 70 mg/l N treatment. In these experiments, the shade used over hoops on benches and as a mobile screen across the top of the compartments was supplemented by opaque polythene covers placed on top of the Perspex lids placed over the troughs in order to minimise the effects of solar radiation. The first experiment compared three species with expected differences in pH preference, these were *Rosa* Red Bells (Poulred) considered to prefer higher pH, Blueberry (*Vaccinium corymbosum* 'Bluecrop') considered to prefer low pH and *Clematis* ‘Dr Ruppel’ considered to have a wide range for pH. The second (July) experiment repeated the main elements of the October experiment with *C.vulgaris* and *E.carnea* on a replicated basis. Treatments included the peat/perlite and grit substrates, 10 mg/l N and 70 mg/l N nutrition treatments as well as pH 2-10 at 10 mg/l N and pH 4-8 at 70 mg/l N.

Unreplicated observation treatments again compared response to pH in the main experimental systems with response to pH in a peat/perlite substrate amended with dolomitic limestone. Lime was added to the substrate at either 0, 3.25, 10 or 20 g/l in the May experiments and this range was extended to 40, 80 and 120 g/l in the July experiments. These treatments were irrigated with R/O water blended with borehole water to deliver a background Ec of 500 µS/cm (at 20°C).

Two replicate troughs of each substrate type x pH x feed combination were used in the May and July experiments with analysis on the mean of the 10 replicate cuttings struck into each treatment. Lime treatments were unreplicated.

Assessments

Cuttings were assessed for rooting progress using the qualitative score system developed in previous years as follows:

Score	**Description**
0	Dead and/or decaying
1	Sound cut surface, no decay
2	Thickening of stem at cut surface or lenticels or development of a distinct callus
3	Root initials, one or several up to 5mm in length
4	Root development/extension, roots 5-10mm but not branching
5	Good root development with branching, sufficient to support growth after potting on

Appendix I illustrates how these scores were used for the species assessed.

Assessments were timed according to when at least one treatment had rooted using informal interim inspections on treatments to trigger assessment dates. The assessments were therefore earlier than in previous years where the aim was to reach 100% score 5s in at least one treatment in interim inspections before carrying out the final to assessment. Cuttings were removed from the substrate carefully and gently washed prior to assessment. Sets of cuttings from each treatment were also photographed.

Root fresh weight was determined after blotting cuttings dry by removing all roots from the stem surface (i.e. excluding the original stem material) in the May and July experiments where there was generally sufficient root material for weights to be reliable; some of the heather cuttings however had insufficient root for accurate measurements and were recorded as a default 0.001 g where this was relevant.

Clematis and blueberry cuttings in the May experiment and some heather cuttings in the July experiment suffered from *Botrytis* infection and therefore losses. Where cuttings were badly infected prior to final assessments, they were removed to minimise infection spread. These cuttings were therefore also scored for infection / general health as an aid to interpreting data. Rovral sprays were also used in the July experiment which appeared to minimise infection spread but unfortunately also introduced another factor into the experiment (all treatments were sprayed at the same time when this was necessary).

Data analysis

The replicated data collected from the main experiments were analysed using analysis of variance. Those species that had been badly affected by disease were analysed in two ways, for all 10 scores even if the score was zero, and for surviving cuttings only. Results from these two methods of analysis were compared and where consistent the scores across all cuttings were used. Mean rooting score was therefore often lower than the fully rooted score 5 figure where the score (or weight) 0 for infected cuttings lowered average data.

RESULTS

For data with significant differences the l.s.d. (least significant difference) value at $p<0.05$ (the probability of this result occurring by chance is equal to or less than 1 in 20) is quoted alongside the data. Where there were no significant differences between the data, n.s. is quoted

Analysis of solutions and substrates

October 2007 experiments

Nutrient solution pH

The pH 6 and 8 treatments were the most variable but the regular monitoring of tanks and adjustment was sufficient to maintain good separation of treatments throughout the experiment (figure 1). These data relate to samples taken from the tank supplying each set of grit and peat/perlite treatments and hence indicates the pH applied to both types of media used.

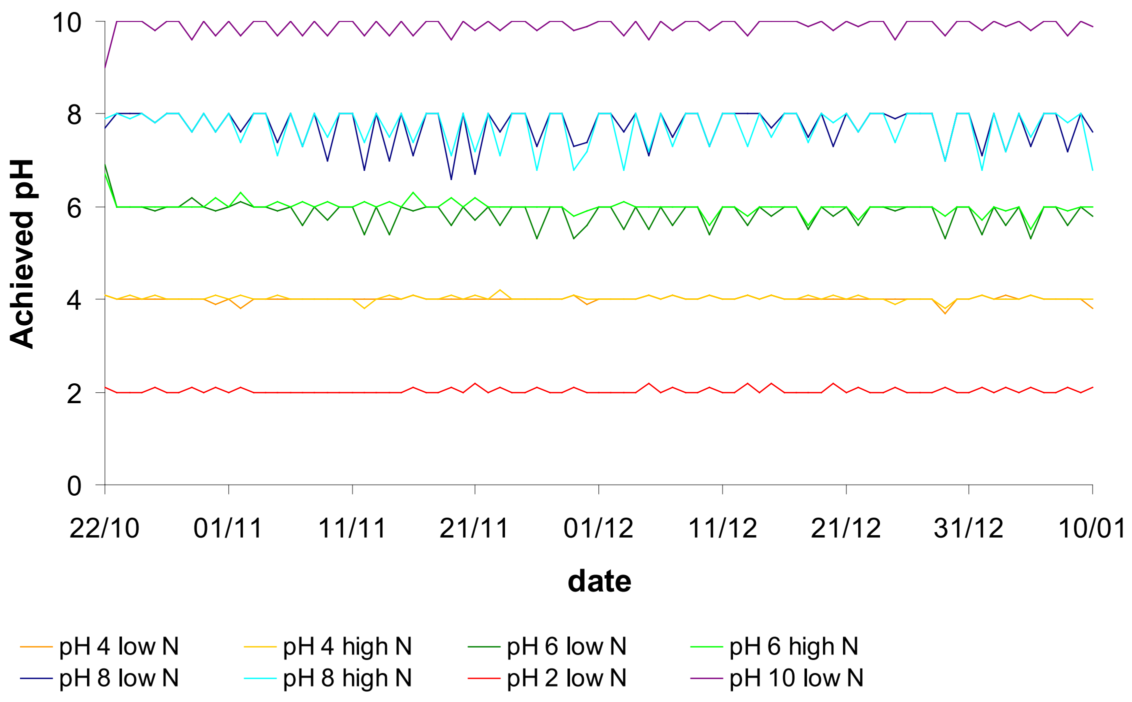


Figure 1: Achieved pHs in nutrient solutions applied to the grit (pH 2-10) and peat/perlite (pH 4-8) substrates in the October 2007 experiment

Un-limed peat/perlite samples

Achieved pH in the peat/perlite substrates analysed at the end of experiment generally followed the target pH for each treatment (figure 2) within the pH 4 to 8 range tested with pH of substrate treated with the 70 mg/l feed slightly lower than that treated with the 10 mg/l feed.

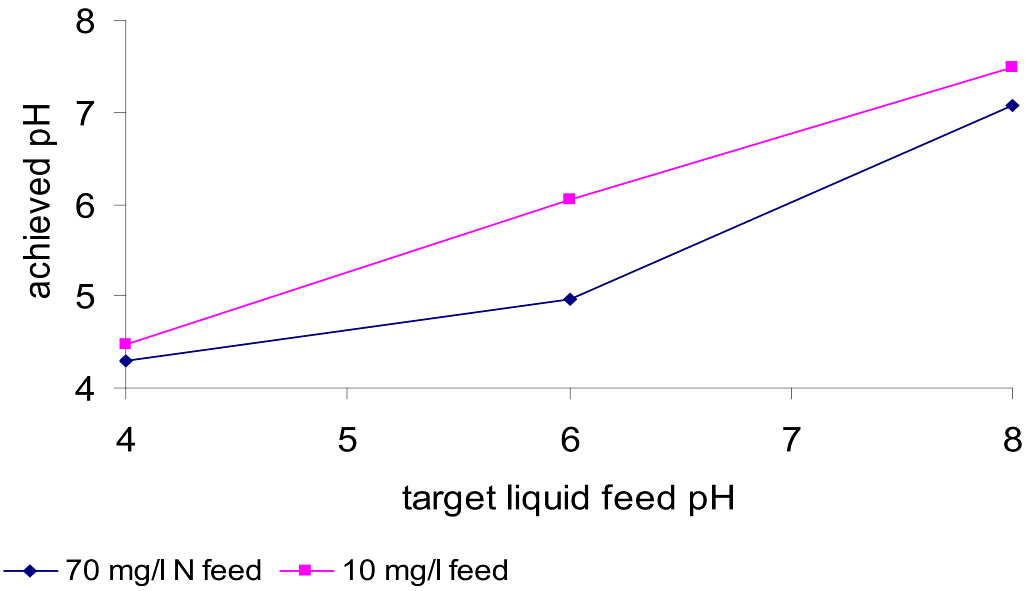


Figure 2: A comparison of achieved pH measured in peat/perlite substrates irrigated with 10mg/l and 70 mg/l N liquid feeds

Limed peat samples

Adding lime to the peat/perlite mix increased substrate pH with the rates used resulted in pHs of 5.1, 6.1 and 6.1 for the 0, 3 and 8.25 g/l rates respectively.

May and July 2008 experiments

Nutrient solution pH

The pH 6 and 8 treatments were the most variable in both the May and July 2008 experiments but the regular monitoring of tanks and adjustment was sufficient to maintain good separation of treatments throughout both experiments (figures 3 and 4). These data relate to samples taken from the tank supplying each set of grit and peat/perlite treatments and hence indicates the pH applied to both types of media used.

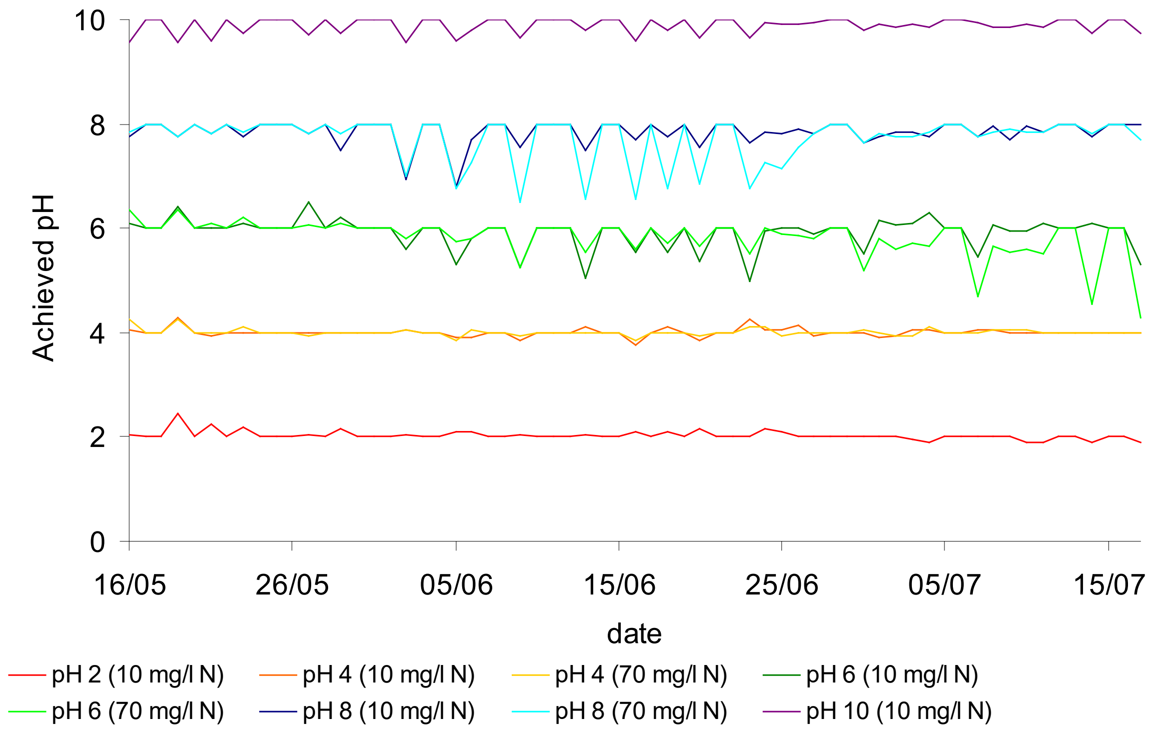


Figure 3: Achieved pHs in nutrient solutions applied to the grit and peat/perlite substrates in the May 2008 experiment

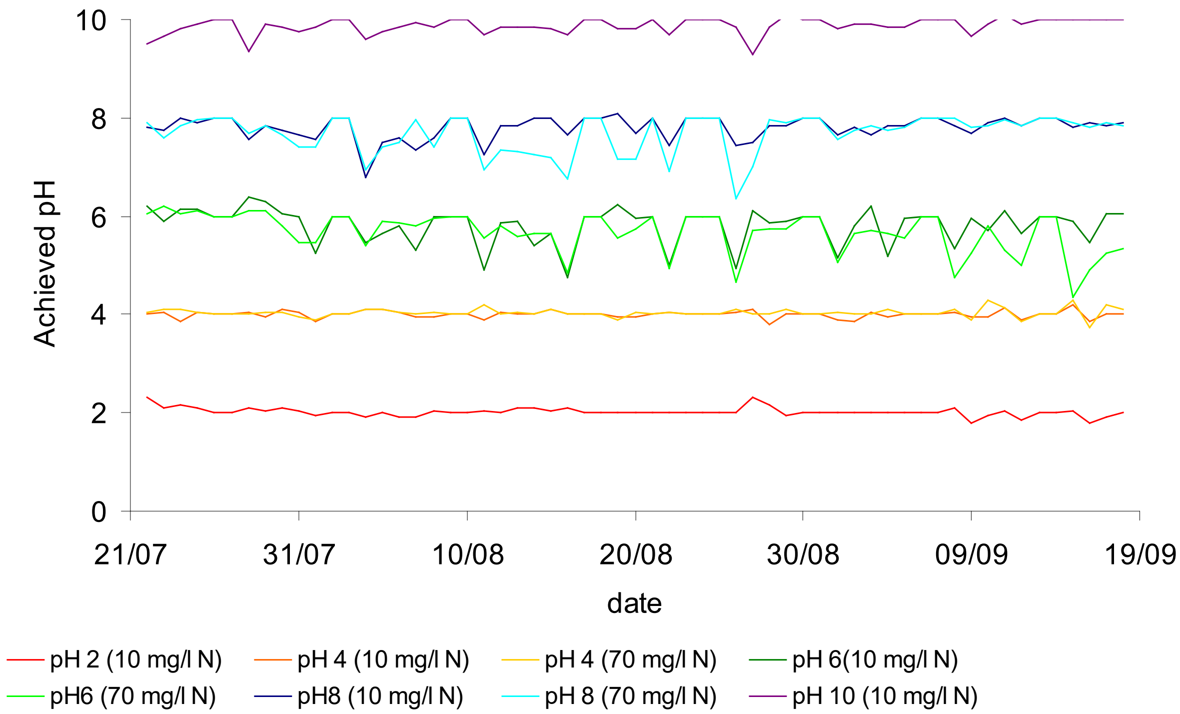


Figure 4: Achieved pHs in nutrient solutions applied to the grit and peat/perlite substrates in the July 2008 experiment

Un-limed peat/perlite samples

The peat/perlite substrates were used unlimed in experiments with pH treatments applied as pH adjusted nutrient solutions. In both the May and July experiments, pH of the substrate analysed at the end of the experiment matched the pH of the applied liquid feed well when the target pH treatment was between 2 and 6 (figure 5). However, at higher target pH, the peat/perlite substrates had lower achieved pH than that of the liquid feed applied, with differences as great as 3 pH units for the pH 10 treatment. Hence for the higher pH treatments in the peat/perlite systems, cuttings apparently enjoyed some buffering from the high pH supplied in the nutrient solution which may have limited the effectiveness of the pH treatments applied and this will need to be considered when interpreting the rooting data.

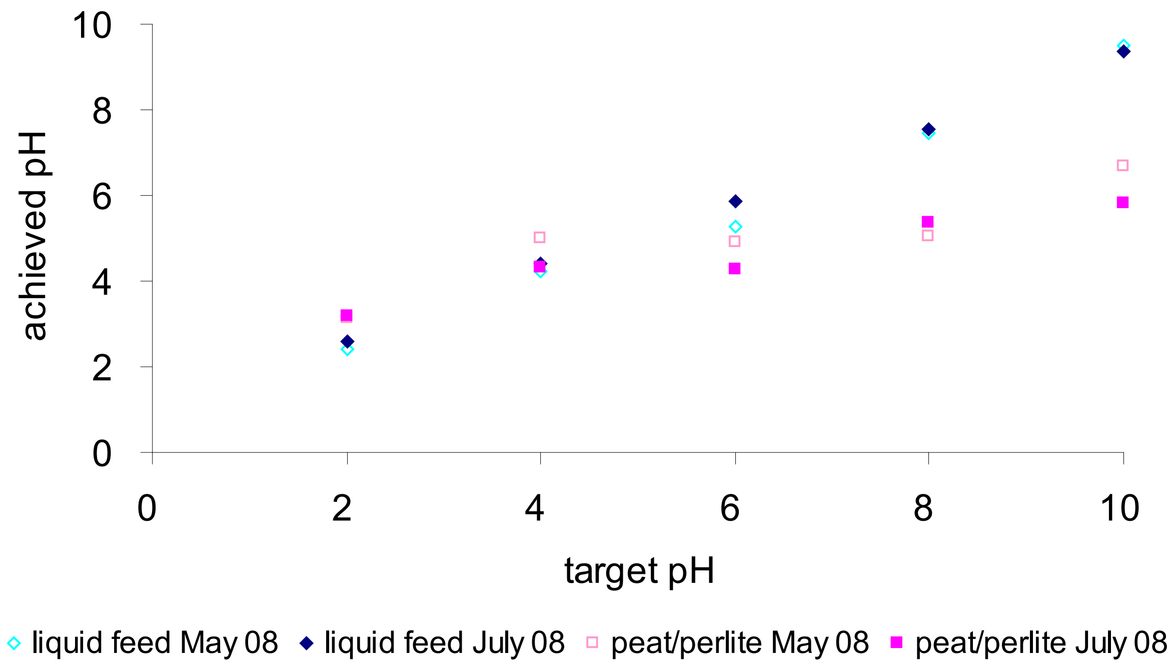


Figure 5: A comparison of achieved pH measured in peat/perlite substrates and in the pH adjusted 10 mg/l N liquid feeds[1]

[1] Note: the analysis for liquid feed in this figure relates to samples taken at the end of experiments. The pH monitoring throughout experiments in figures 3&4 give a better picture of pH during the experiment overall.

Nutrient solution adjusted to pH 2 had significantly higher conductivity (2481 µS/cm at 20°C) than solution at pH 4-8 (592-647 µS/cm at 20°C). These differences were linked to an increase in S, probably originating from the sulphuric acid used to adjust pH and also to an increase in Na and Fe. The pH 10 solution also had higher conductivity (1052 µS/cm at 20°C) than at pH 4-8 and was in this case linked to higher Na from the use of sodium hydroxide to raise pH.

Table 2: Mineral analysis data from pH adjusted nutrient solution at 10 mg/l N in the July 2008 experiment

Target pH	Conductivity (µS/cm 20°C)	NO_3-N (mg/l)	NH_4-N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)
2	2481.00	4.85	4.98	14.31	15.34	3.00	2.95
4	605.35	4.87	4.91	14.56	16.09	3.20	3.29
6	592.30	10.54	0.00	13.46	15.43	3.04	3.15
8	647.35	11.37	0.00	14.66	16.23	3.23	3.37
10	1052.00	7.30	0.00	15.15	15.63	3.19	2.85

Target pH	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	Cl (mg/l)	S (mg/l)
2	0.08	0.14	0.04	0.02	0.08	337.39	86.08	267.98
4	0.02	0.10	0.04	0.01	0.08	97.56	106.63	47.89
6	0.01	0.13	0.01	0.01	0.08	107.11	93.36	38.84
8	0.01	0.03	0.00	0.01	0.08	128.07	106.26	29.22
10	0.01	0.02	0.00	0.03	0.10	268.12	99.24	27.34

Concentrations of NH_4-N, K, Ca, Mg, Zn, Mn, Fe, B, Cu, S and Cl were notably higher (table 3) in the peat/perlite substrates irrigated with the pH 2 nutrient solution compared with the pH 4-8 solutions (July 2008 experiments) and consequently substrate conductivity increased from an average of 49-53 µS/cm (20°C) for the pH 4-8 treatments to 239-245 µS/cm (20°C) for the pH 2 treatment (for treatments on low feed irrigation). This reflects the increases associated with the pH 2 nutrient solution but also extends to a wider range of elements. To put this into context, average conductivity from peat/perlite samples irrigated with the higher N feed at pH 4-8 was 82 µS/cm (20°C). Whilst the use of sulphuric acid to lower pH of nutrient solution would be expected to increase S concentration, this cannot account for the increase in concentration of other elements.

Samples of grit were not included in the routine media analyses but retrospective tests were carried out using the 10 mg/l N nutrient solution at pH 2 and 4 to replicate the pre-conditioning procedure that had been used for this media in experiments. The conductivity of the solution used to pre-condition the grit was again higher (up to 270µS/cm 20°C) for the pH 2 treatment than for the pH 4 treatment (up to 85µS/cm 20°C).

Table 3: Mineral analysis data from peat/perlite substrates in the July 2008 experiment irrigated with low N nutrient solutions at different pH

Target pH	Conductivity (µS/cm 20°C)	NO_3-N (mg/l)	NH_4-N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)
2	239.40	5.19	3.29	13.16	26.54	16.90	2.08
4	51.05	4.31	0.72	7.82	2.07	0.79	1.47
6	54.20	6.56	0.15	8.14	2.87	1.30	2.28
8	40.92	1.58	0.00	5.21	1.19	0.45	1.54
10	41.64	1.02	0.00	4.58	1.60	0.55	1.25

Target pH	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	Cl (mg/l)	S (mg/l)
2	0.31	0.85	0.13	0.08	0.10	123.30	68.77	118.32
4	0.38	0.07	0.01	0.02	0.06	83.85	47.58	23.98
6	0.53	0.08	0.01	0.02	0.05	92.27	60.26	21.36
8	0.52	0.07	0.01	0.04	0.09	72.37	57.52	16.08
10	0.97	0.06	0.01	0.04	0.06	73.05	60.47	12.96

Similarly, peat/perlite substrates analysed at the end of the May 2008 experiment had elevated ion concentrations following irrigation with the pH 2 nutrient solution (table 4). The range of ions affected by the pH 2 irrigation was smaller in these earlier experiments. This overall trend however suggests reactions occurring within the substrate at this low pH, possibly resulting in the oxidation of peat particles, releasing extra ions into solution. Interpretation of rooting data should therefore consider the differences in nutrient concentration as well as in pH as a result of the treatments applied.

Table 4. Mineral analysis data from peat/perlite substrates in the May 2008 experiment irrigated with low N nutrient solutions at varying pH.

Target pH	Conductivity (µS/cm 20°C)	NO_3-N (mg/l)	NH_4-N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)
2	244.90	3.81	2.09	12.72	5.02	1.16	1.86
4	68.91	9.24	0.61	8.85	1.49	0.43	1.11
6	47.74	5.23	0.00	7.17	0.94	0.33	0.83
8	43.67	4.34	0.00	4.55	0.75	0.33	1.51
10	41.42	4.58	0.00	3.31	1.19	0.47	0.85

Target pH	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	Cl (mg/l)	S (mg/l)
2	0.32	0.97	0.04	0.07	0.07	151.63	79.69	101.35
4	0.83	0.12	0.01	0.06	0.09	182.35	94.47	44.43
6	0.62	0.07	0.01	0.03	0.09	106.09	70.87	21.43
8	0.60	0.04	0.01	0.01	0.07	79.19	65.09	14.04
10	1.16	0.10	0.01	0.04	0.12	100.21	53.84	15.72

Limed peat/perlite samples

At lower rates of lime addition (0 to 20g/l), pH of the peat/perlite substrates measured at the end of experiments initially increased with increased rate of lime up to the 40 g/l rate (figure 6) with the 0 rate providing a comparable pH to the pH 4 treatment of the main trial, the 3.25g/l rate was close to pH 6 and the 40 g/l close to pH 8. At 40 g/l of lime and above, substrate pH stabilised at around 7.5 to 7.8 despite significant further additions of lime (i.e. up to 120 g/l).

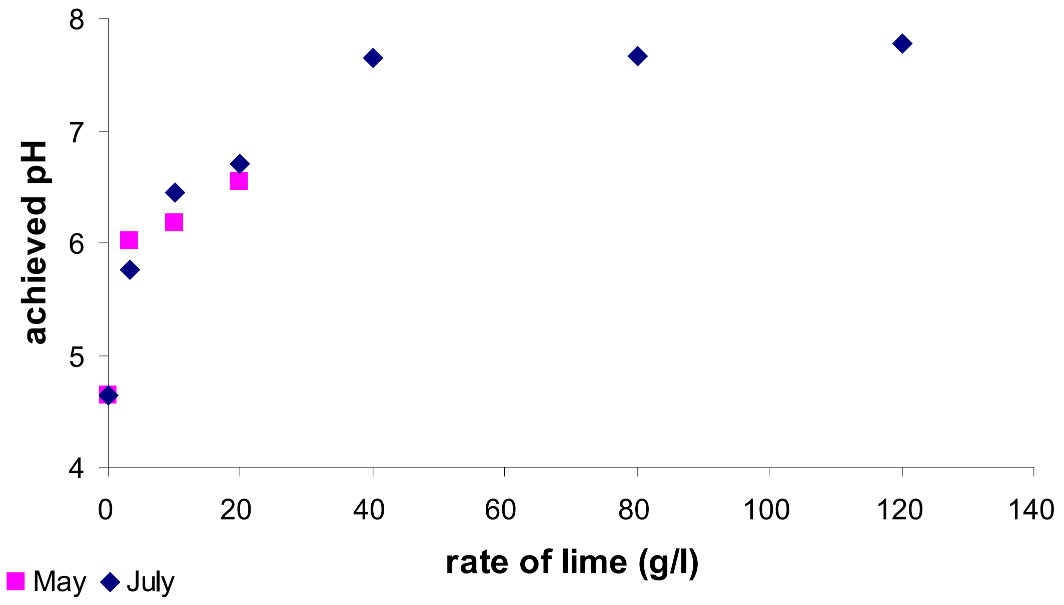


Figure 6: The influence of lime rate on pH of peat/perlite substrates

Ca and Mg concentration also increased as rate of lime increased (figures 7&8). Unlike pH, which stabilised at 40 g/l of lime and above, Ca and Mg concentration available in the substrate continued to increase as rate of lime increased up to the highest rate used (120 g/l).

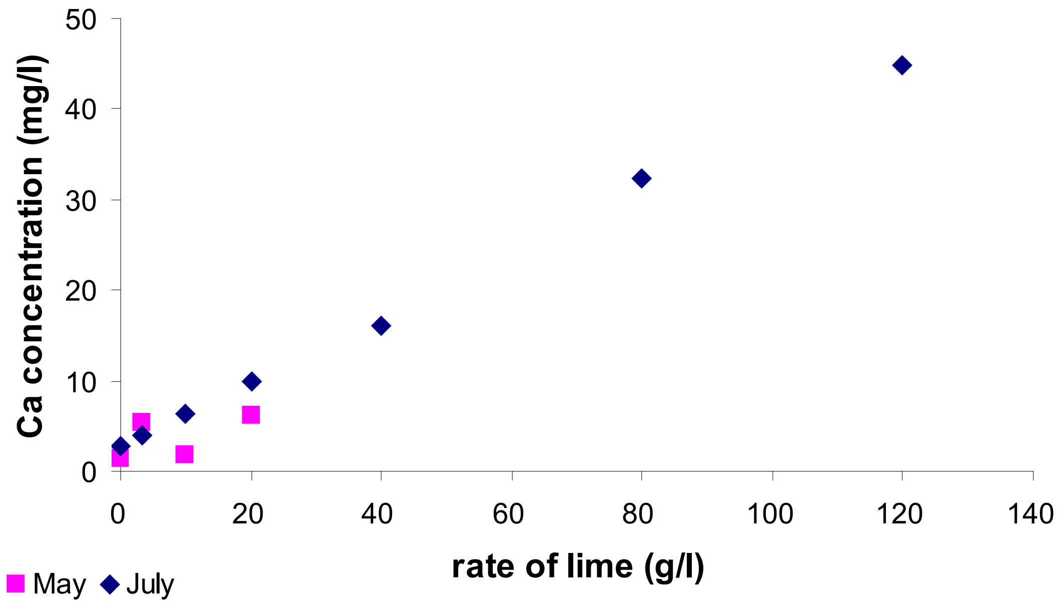


Figure 7: The influence of lime rate on calcium concentration in peat/perlite substrates

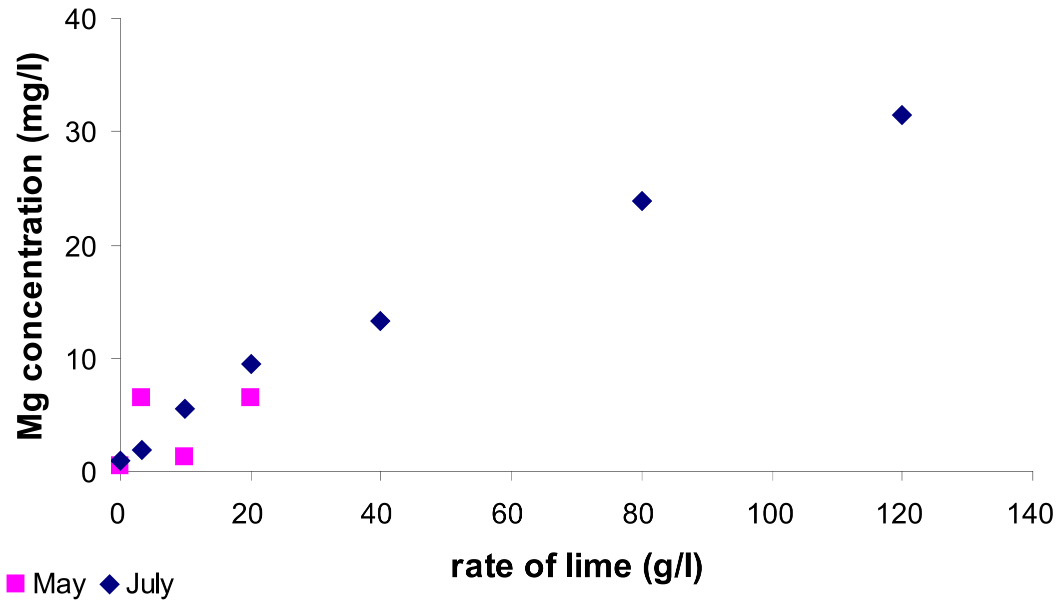


Figure 8: The influence of lime rate on magnesium concentration in peat/perlite substrates

Ca in limestone replaces H+ ions associated with the peat with the H+ in solution converting to H_2O. It appears that all the available H+ associated with the peat had been displaced at around pH 7.7 (i.e. 40 g/l rate of addition). Further addition of limestone increased Ca and Mg availability but no longer influenced substrate pH.

Although the limed peat had no base fertiliser incorporated, higher rates of lime (40 g/l and above) were associated with increased concentration of other nutrient ions (table 5). Since some of these elements, e.g. P, Fe, Mn, B would be expected to become less available in peat based substrates at higher pH (Bunt, 1988), and since pH became quite stable at these rates of lime, the increases seem unlikely to be related to pH induced changes in availability. It is assumed that these nutrient ions originated from impurities within the lime used which was a standard horticultural grade of product. The general increase in mineral ions resulting from the higher rates of lime increased substrate conductivity from around 42 µS/cm (at 20°C) to 79 µS/cm (at 20°C) which is similar to the differences in substrate conductivity between the 10 and 70 mg/l N treatments.

Table 5: Mineral analysis data from limed peat/perlite substrates sampled at the end of experiments

Rate of Lime (g/l)	EC (µS/cm 20°C)	NO_3-N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)
0.00	41.49	4.18	5.03	2.84	0.88	0.70
3.25	42.47	2.80	6.48	3.93	1.89	0.65
10.00	50.83	6.75	5.21	6.35	5.49	0.99
20.00	61.18	7.10	6.48	9.96	9.44	0.78
40.00	63.88	5.93	16.48	20.79	16.51	2.12
80.00	78.73	6.30	19.64	35.42	26.65	2.43
120.00	79.09	4.10	21.35	53.65	37.36	2.39

Rate of Lime (g/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	Cl (mg/l)	S (mg/l)
0.00	0.31	0.04	0.01	0.07	0.06	60.68	59.41	14.18
3.25	1.06	0.10	0.02	0.11	0.05	66.02	40.25	14.20
10.00	1.04	0.07	0.03	0.07	0.03	66.67	58.70	13.71
20.00	1.63	0.05	0.04	0.08	0.03	61.53	48.47	14.56
40.00	9.38	0.16	0.22	0.17	0.27	94.67	74.85	19.58
80.00	13.08	0.23	0.31	0.18	0.27	106.20	72.00	25.11
120.00	19.25	0.21	0.44	0.16	0.15	102.88	66.38	25.44

Rooting data

October 2007 experiments

Calluna vulgaris 'Allegro'

Main pH effects

Analyses were carried out for each substrate type separately. The highest root scores within each substrate type were achieved at pH 4 and 6 within the range tested and the lowest scores were from rooting at pH 2.

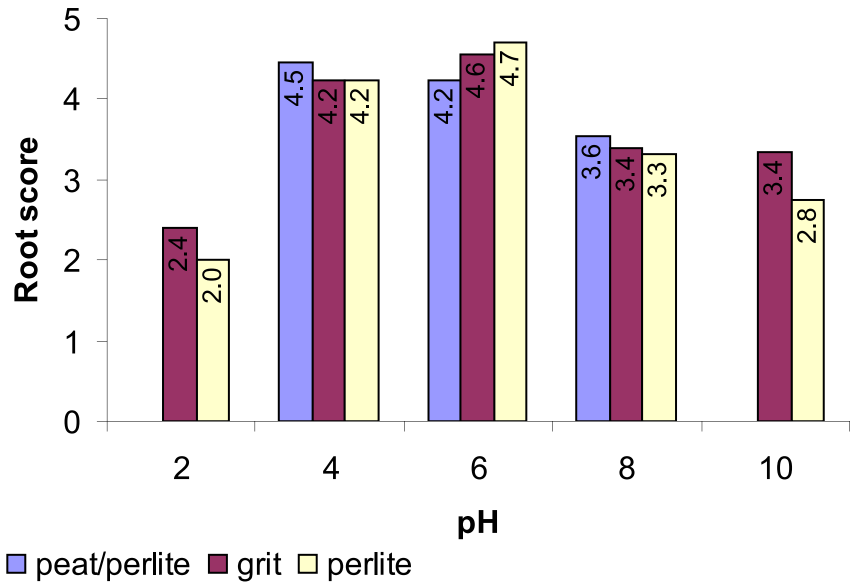


Figure 9: The effects of pH and substrate type on rooting in *Calluna vulgaris* (l.s.d. = 0.34 for peat/perlite, 0.41 for grit, 0.35 for perlite)

Interaction between pH and transfers

In peat/perlite at pH 4 and 6, root scores of the direct struck cuttings were no different to those of the transferred cuttings, despite the potential disturbance that transplanting might be expected to create. At pH 8, direct struck cuttings had lower root score than transferred cuttings suggesting pH 8 had limited initial root development in this substrate.

Similar results occurred in the grit and perlite substrates. That is, at pH 4 and 6 where root scores were higher, direct struck cuttings had higher root score than transferred cuttings. The transfer from peat/perlite to grit or perlite may have created greater disturbance than for the transfer between peat/perlite systems described above. At pH 8 and 10 however, where pH was apparently restricting rooting, transferred cuttings had higher root score than direct struck cuttings. A similar result occurred at pH 2 for both substrates but with a greater difference between the direct struck and transferred cuttings. These results suggest than initial stages of rooting did respond to pH treatments where these treatments were capable of creating a difference. The reduction in root score of transferred cuttings for pH 2 compared with pH 4 and 6 suggests that later root development had also responded to the pH 2 treatment.

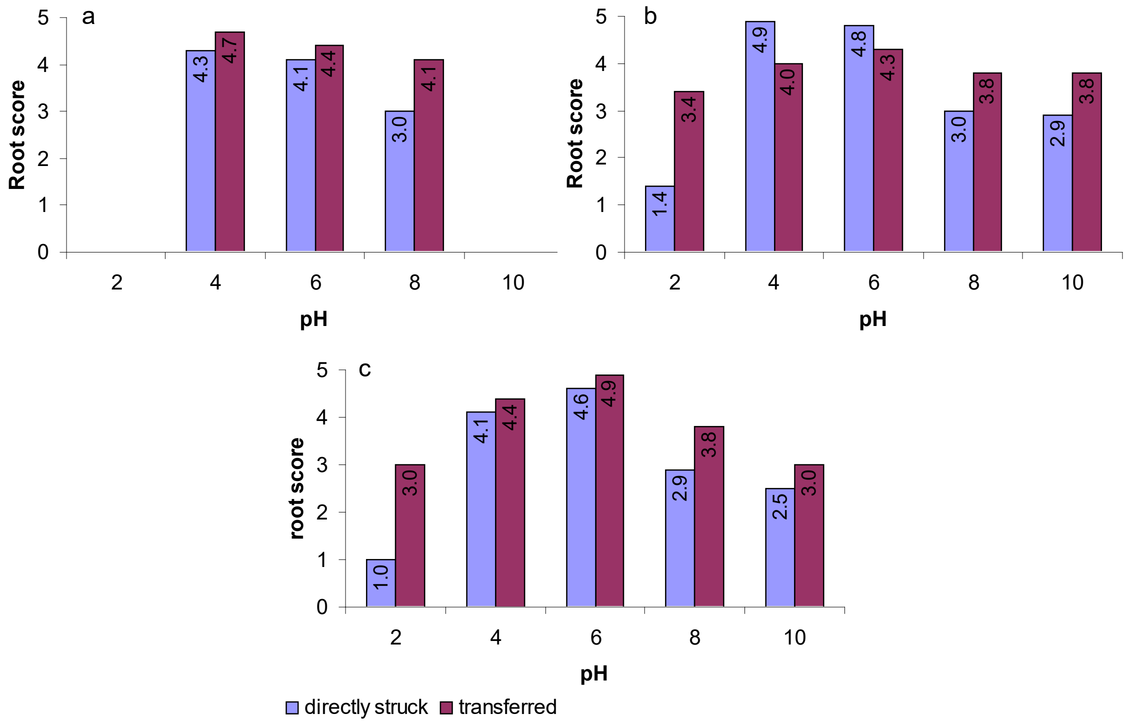


Figure 10: Interaction between pH and transfers on root scores of *Calluna vulgaris* (l.s.d. = 0.48 (a, peat/perlite), 0.59 (b, grit), 0.50 (c, perlite))

Interaction between pH and nutrient concentration

Root score was generally lower in treatments receiving the 70 g/l feed compared with the 10 mg/l. The differences between these treatments were greater at pH 8 than at pH 4 or 6 which suggests that the effects of this higher pH were compounded by the higher nutrient concentration applied.

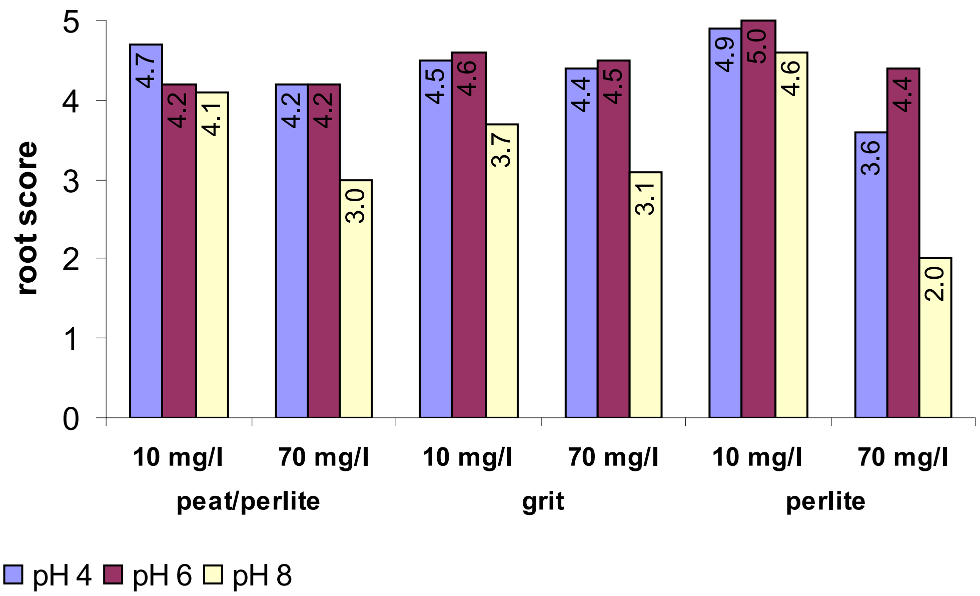


Figure 11: Interaction between pH and nutrient concentration on root scores of *Calluna vulgaris* (l.s.d. = 0.50 (peat/perlite), 0.50 (grit), 0.38 (perlite))

***Erica carnea* 'Pink Spangles'**

Main pH effects

Analyses were carried out for each substrate type separately. There were no significant effects of pH on cuttings in peat/perlite. Cuttings at pH 2 had the poorest root score overall in both the grit and perlite treatments. Although there were slight differences between root scores between pH 4 and 10, effects were small and given the high scores achieved at pH 10 there was no consistent evidence of decline in root score due to increase in pH.

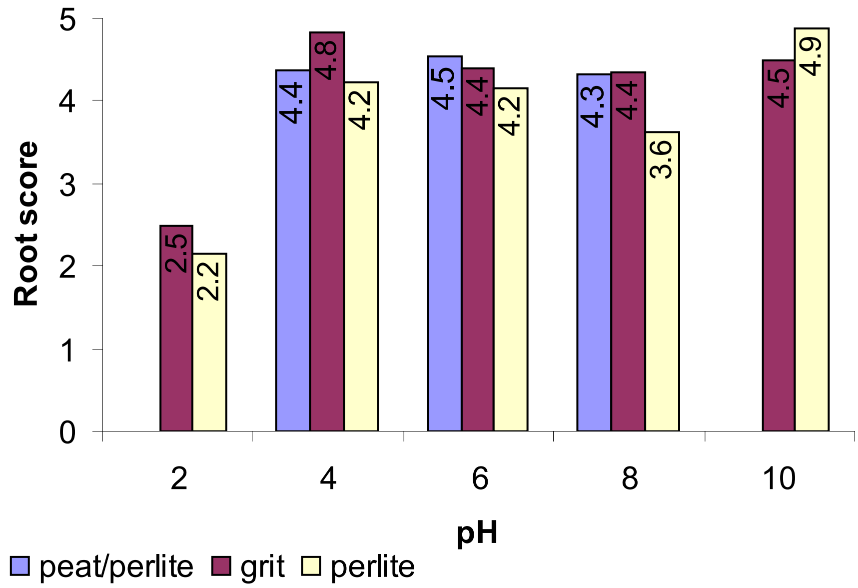


Figure 12: The effects of pH and substrate type on rooting in *Erica carnea* (l.s.d. = ns (peat/perlite), 0.31 (grit), 0.26 (perlite))

Interaction between pH and transfers

As with *Calluna vulgaris*, transferred cuttings were the same as direct struck cuttings in terms of response to pH in peat/perlite. In grit, direct struck and transferred cuttings were also comparable at pH 4 and 6 but root score was higher for the transferred cuttings at pH 2, 8 and 10. The difference between transferred and direct struck cuttings was greater at pH 2 where response to pH was greater. Results were less consistent in perlite with lower root score associated with the direct struck cuttings at pH 6 and 8 but no difference at pH 10. At pH 2 however results were similar to those in grit with the greatest reduction in root score in the direct struck cuttings.

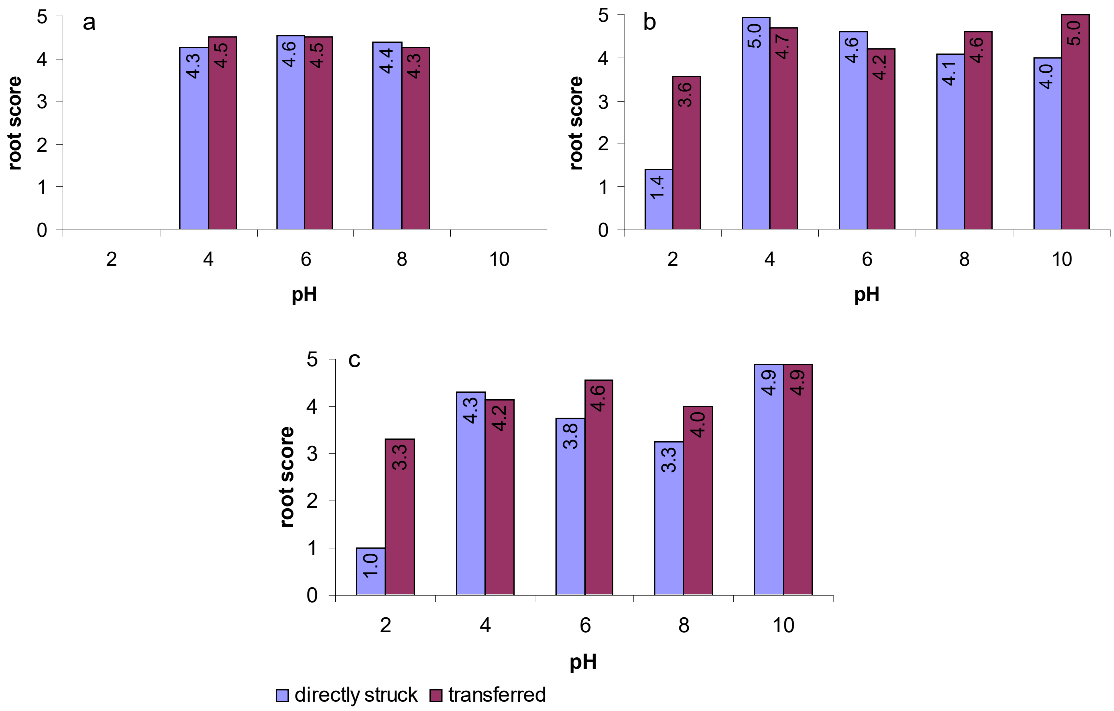


Figure 13: Interaction between pH and transfers on root scores of *Erica carnea* (l.s.d. = ns (a, peat/perlite), 0.44 (b, grit), 0.63 (c, perlite))

Interaction between pH and nutrient concentration

Results were similar to those for *Calluna* vulgaris. That is, root score was generally lower in peat/perlite and perlite treatments receiving the 70 g/l feed compared with the 10 mg/l feed, the differences between these treatments were greater at pH 8 than at pH 4 or 6. This suggests that the effects of this higher pH were compounded by the higher nutrient concentration applied. There were however no significant differences relating to nutrient concentration within the same pH for cuttings in grit.

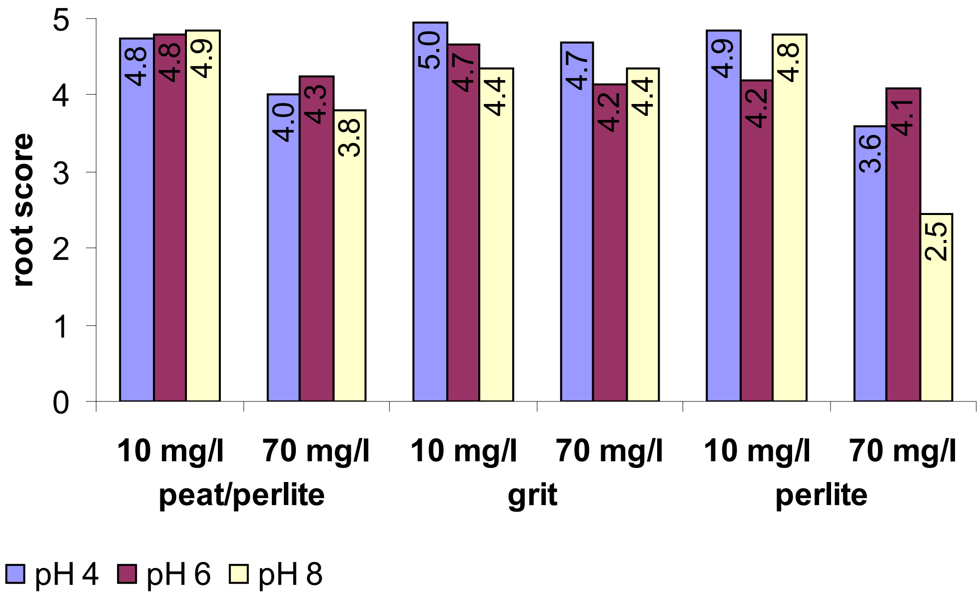


Figure 14: Interaction between pH and nutrient concentration on root scores of *Calluna vulgaris* (l.s.d. = 0.50 (peat/perlite), 0.50 (grit), 0.38 (perlite))

Experiments with limed peat/perlite substrates

Adding lime to peat/perlite increased pH from 5.1 to 6.1 (3 g/l) and 6.9 (8.25 g/l). This had no influence over rooting in *E.carnea* but reduced rooting in *C.vulgaris* at the highest rate of lime used compared with no lime.

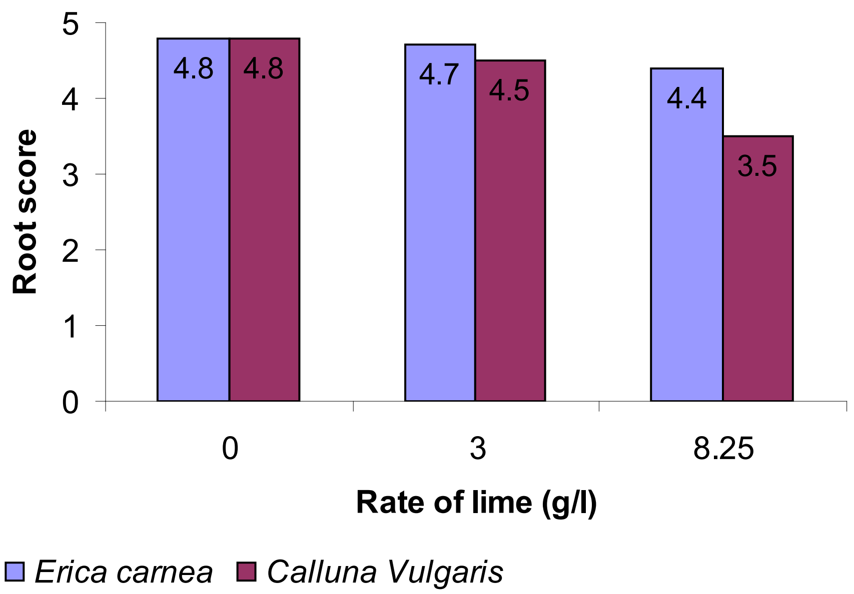


Figure 15: The influence of rate of lime on rooting in peat/perlite (l.s.d. = ns (*E.carnea)*, 0.58 (*C.vulgaris*))

May and July 2008 experiments

Blueberry (*Vaccinium corymbosum* 'Bluecrop')

Root fresh weight

Cuttings rooted in peat/perlite with 10 mg/l N nutrient had significantly lower root weight at pH 2 with no further significant differences at higher pH. There were no differences in rooting between pH levels where the 70 mg/l N feed was used or between the 10 and 70 mg/l N concentrations.

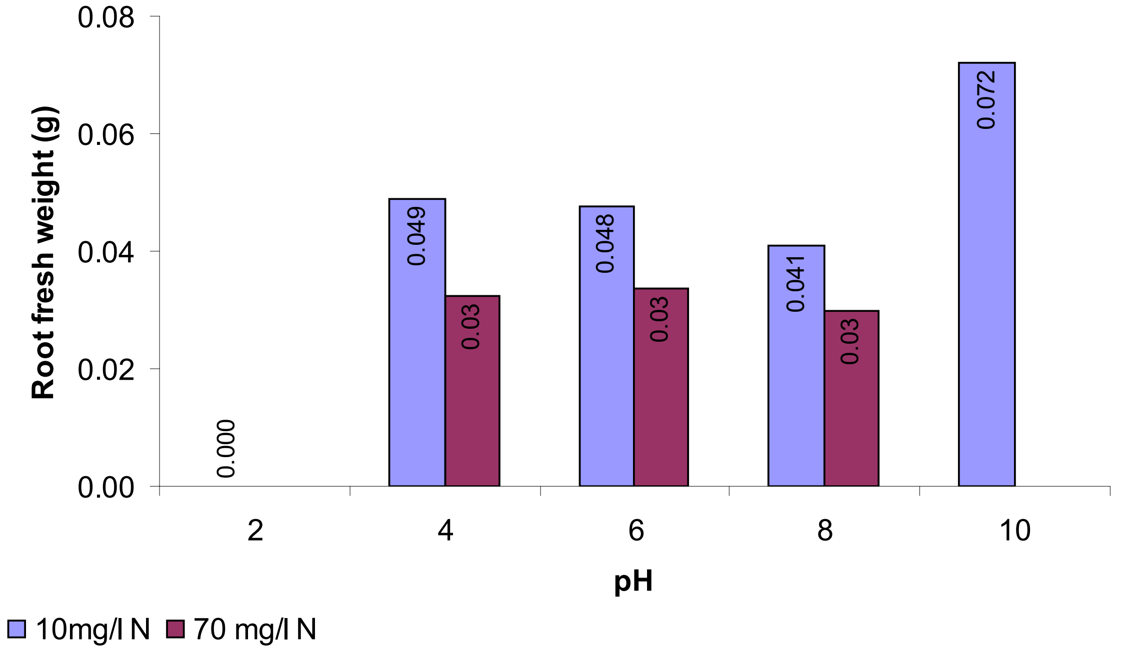


Figure 16: Root fresh weight for Blueberry cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.035)

All cuttings rooted in grit had lower root fresh weight than in peat/perlite (up to 0.013g) and there were no significant differences relating to either pH or feed.

Root score

Root score in peat/perlite was lower for the 10 mg/l N pH 2 treatment with no significant differences at higher pH.

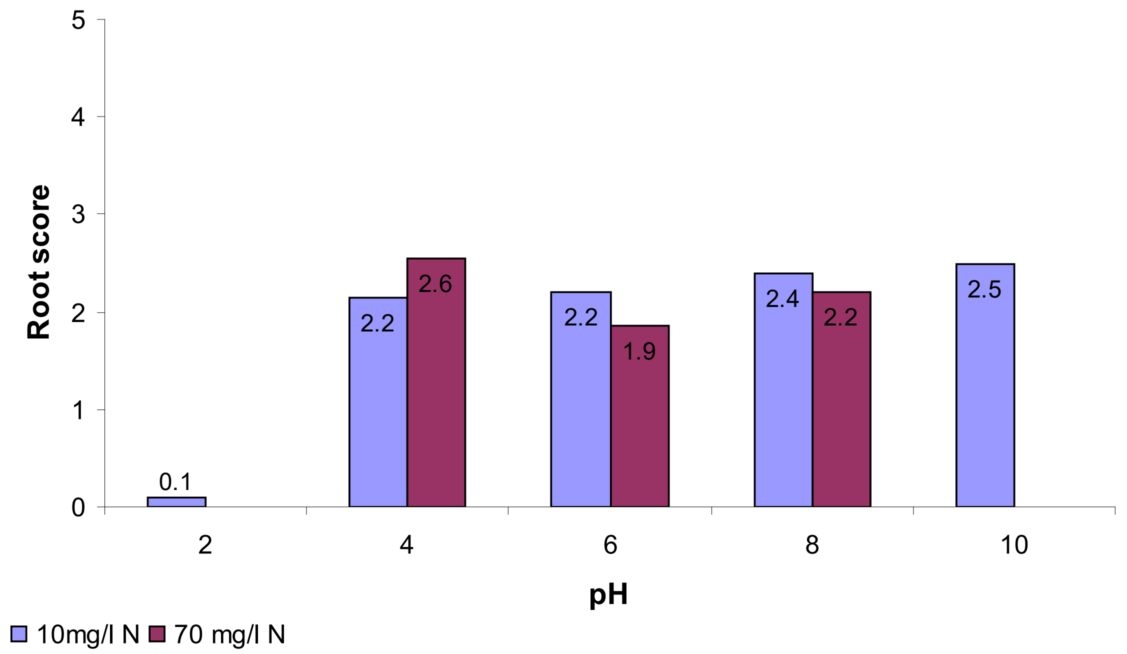


Figure 17: Root score for Blueberry cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.088)

Blueberry cuttings raised in grit generally had a lower root score than when raised in peat/perlite. Cuttings in the 10 mg/l N pH 2 treatment had a lower root score than the remaining treatments. Cuttings in the pH 6 10 mg/l grit treatment had higher root score than the remaining pH treatments combined with the 10 mg/l N feed. There were no significant differences between pH levels combined with the 70 mg/l N feed.

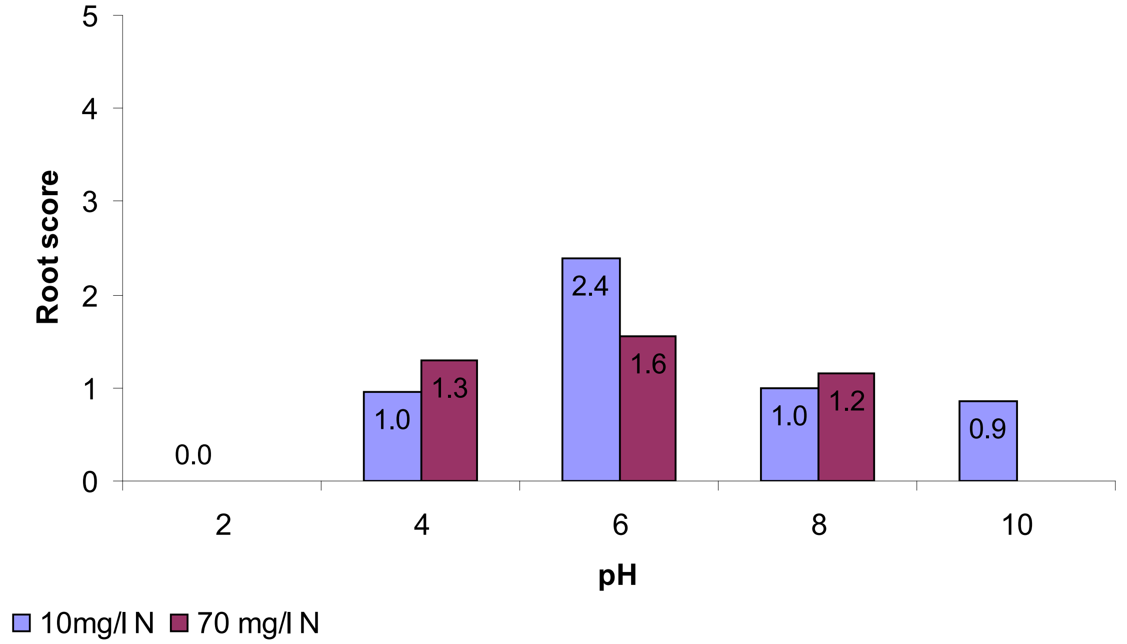


Figure 18: Root score for Blueberry cuttings rooted in grit (l.s.d. (P<0.05) = 0.088)

Overall Blueberry rooting was consistently limited in the pH 2 treatment. Beyond this, rooting score in grit at pH 6 was better than the remaining pH treatments when combined with the 10 mg/l feed but this was not seen in the root weight data where pH had no significant effect between pH 4 and 10. Blueberry did suffer with relative high levels of *Botrytis* infection in these experiments which may be confounding the data collected. Analyses of apparently uninfected cuttings were performed along with analyses including both infected and uninfected cuttings with both sets of data generating comparable results however it is possible cuttings had variable levels of infection that was not yet apparent which may also have been influencing rooting.

***Clematis* 'Dr Ruppel'**

Botrytis infection was most severe on the *Clematis* cuttings with around 22-25% of cuttings severely affected. Furthermore when trends in data between all cuttings (i.e. infected and apparently healthy) and only cuttings apparently healthy were compared, any apparent treatment effects were inconsistent. This level of variation was reflected in the statistical analyses where there were no significant treatment effects on root fresh weight in either the peat/perlite or grit treatments.

Rosa Red Bells (Poulred)

Root fresh weight

Cuttings rooted at pH 2 had the lowest root fresh weight with no differences at higher pH or due to feed concentration.

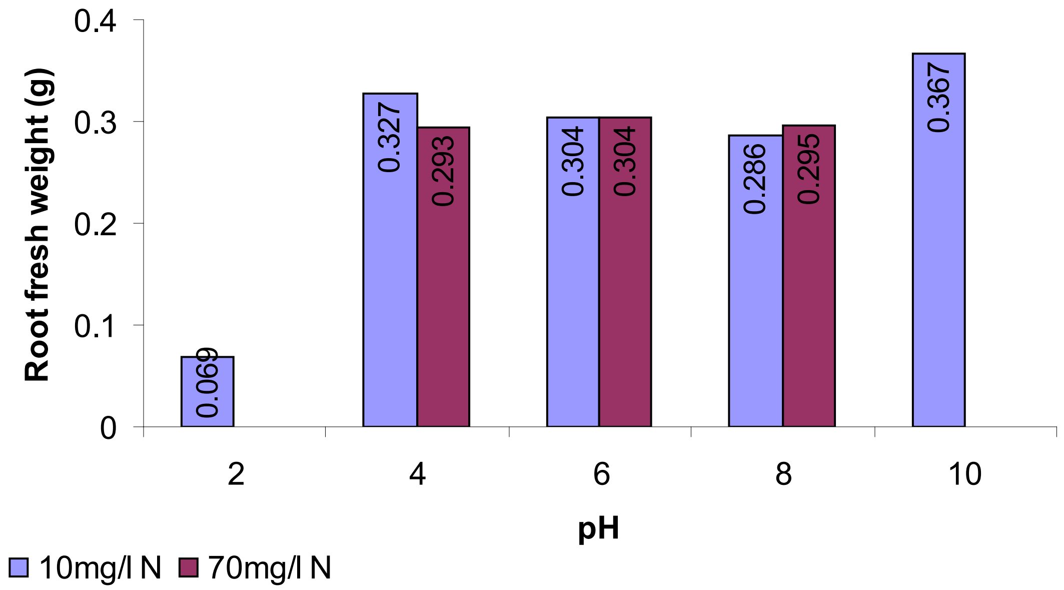


Figure 19: Root fresh weight for Rose cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.092)

The lowest root fresh weight for cuttings rooted in grit resulted from irrigation with the 10 mg/l N feed at pH 2. Fresh weight was comparable between the remaining treatments.

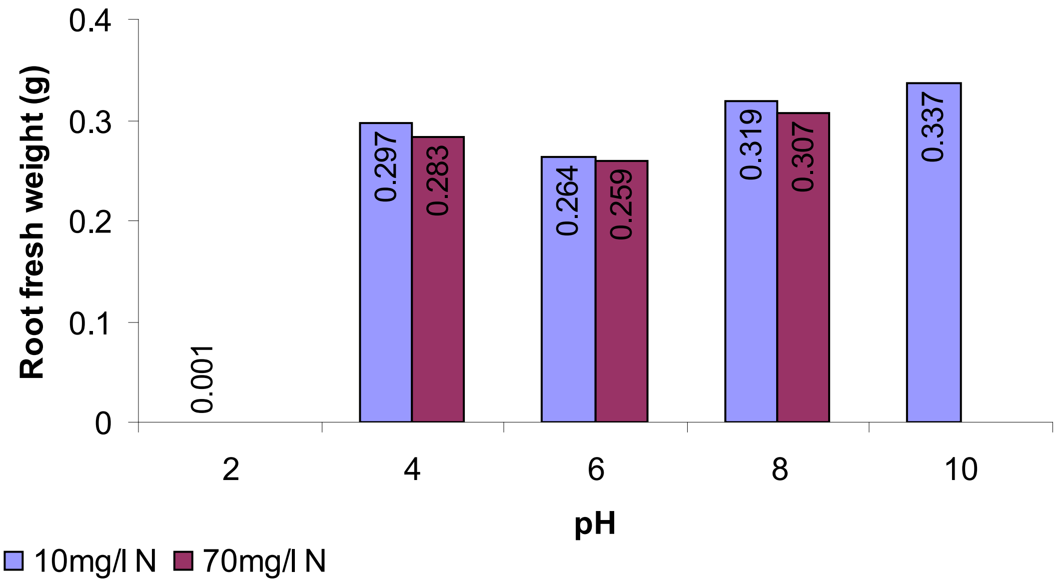


Figure 20: Root fresh weight for Rose cuttings rooted in grit (l.s.d. (P<0.05) = 0.092)

Root score

For cuttings rooted in peat/perlite, root scores reflect the fresh weight data with pH 2 producing the lowest score and no further differences between high pH treatments or due to feed concentration.

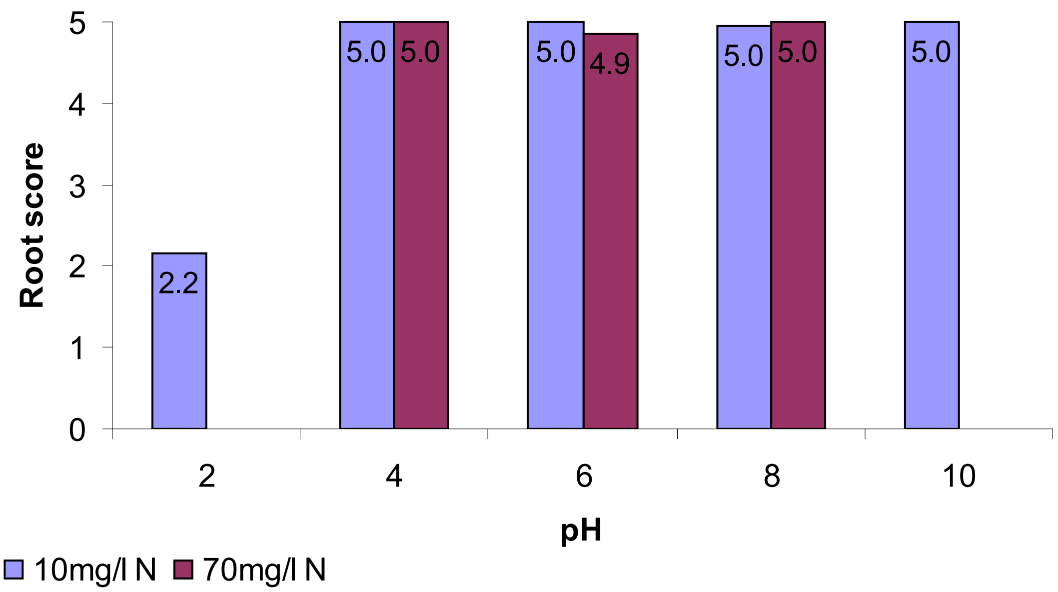


Figure 21: Root score for Rose cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.62)

Cuttings rooted in grit also had the lowest root score at pH 2. With the low feed treatment, pH 4 had a lower root score than pH 10 but overall differences at pHs higher than 2 were small.

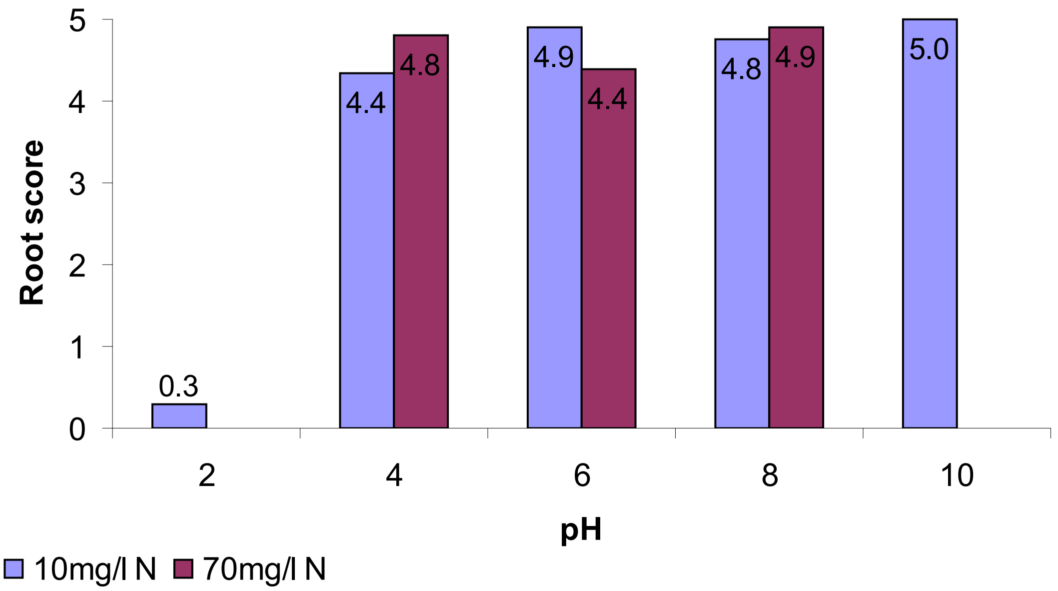


Figure 22: Root score for Rose cuttings rooted in grit (l.s.d. (P<0.05) = 0.62)

***Calluna vulgaris* 'Allegro'**

Root fresh weight (g)

Cuttings in peat/perlite did not root in the 10 mg/l N pH 2 treatment and were also poor in the 10 mg/l N pH 10 treatment compared with pH 4-8. Higher feed concentration (70 mg/l N) was detrimental to root fresh weight compared with the 10 mg/l N feed.

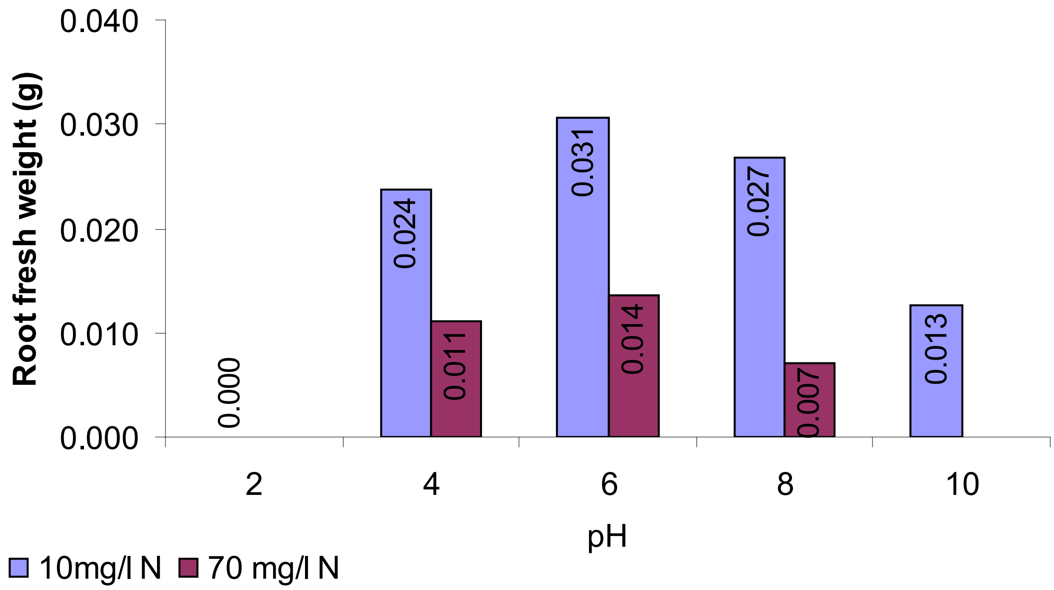


Figure 23: Root fresh weight for *Calluna vulgaris* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.0105)

All Cuttings rooted in grit had lower fresh weight than in peat/perlite and despite apparent trends in the data; none of the differences between treatments were larger than the l.s.d. value indicating no significant differences between treatments.

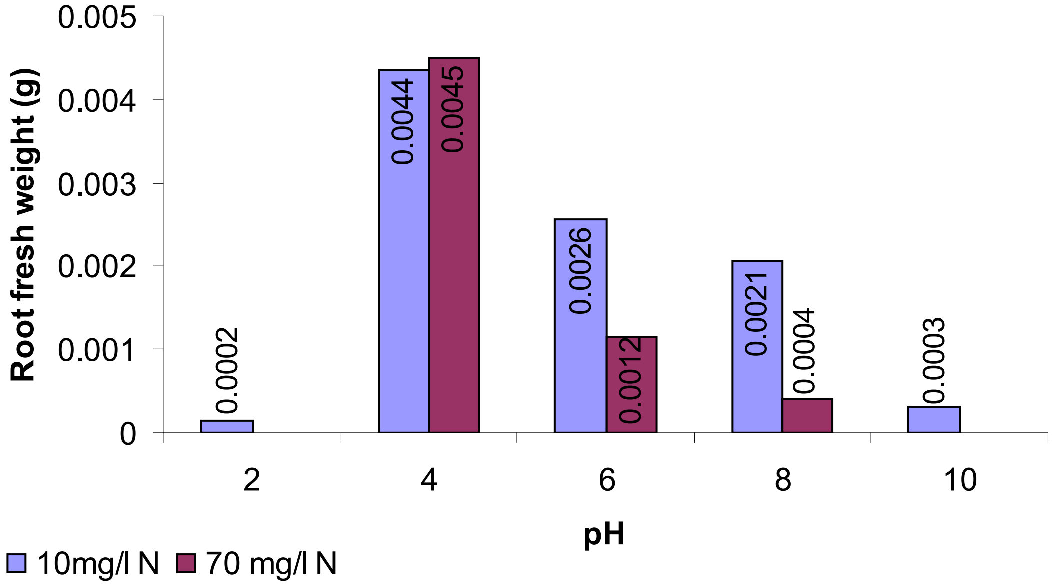


Figure 24: Root fresh weight for *Calluna vulgaris* cuttings rooted in grit (l.s.d. ($P<0.05$) = 0.0105)

Root score

As with root fresh weight, cuttings raised in the 10 mg/l N pH 2 peat/perlite treatment had the lowest root score and pH 10 was also poorer than the rest of the 10 mg/l N treatments. Rooting was comparable between pH 4 and 8 in the 10 mg/l N treatment and was poorer overall in the 70 mg/l N feed compared with the 10 mg/l N feed.

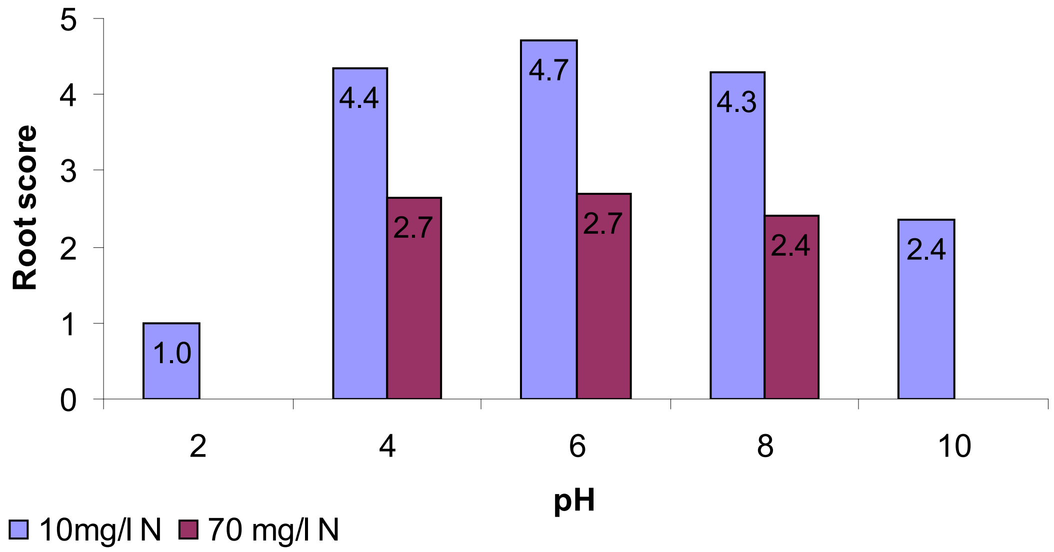


Figure 25: Root score for *Calluna vulgaris* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 1.82)

Root scores were low for all treatments rooted in grit and there were no significant differences between treatments. Peat/perlite produced better rooting overall than grit.

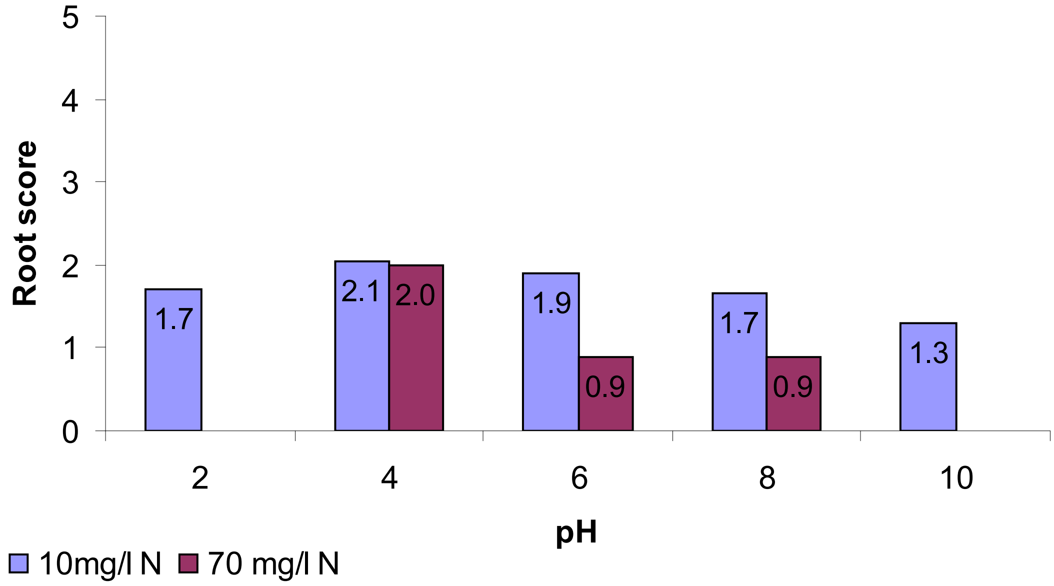


Figure 26: Root score for *Calluna vulgaris* cuttings rooted in grit (l.s.d. (P<0.05) = 1.82)

Cranberry (Vaccinium oxycoccos)

Root fresh weight

For cuttings rooted in peat/perlite, pH 2 at 10 mg/l N produced the lowest root fresh weight, with no further differences within the pH 4-10 range. There were no differences between pH treatments for cuttings receiving the 70 mg/l N feed. Concentration of liquid feed did not influence root fresh weight.

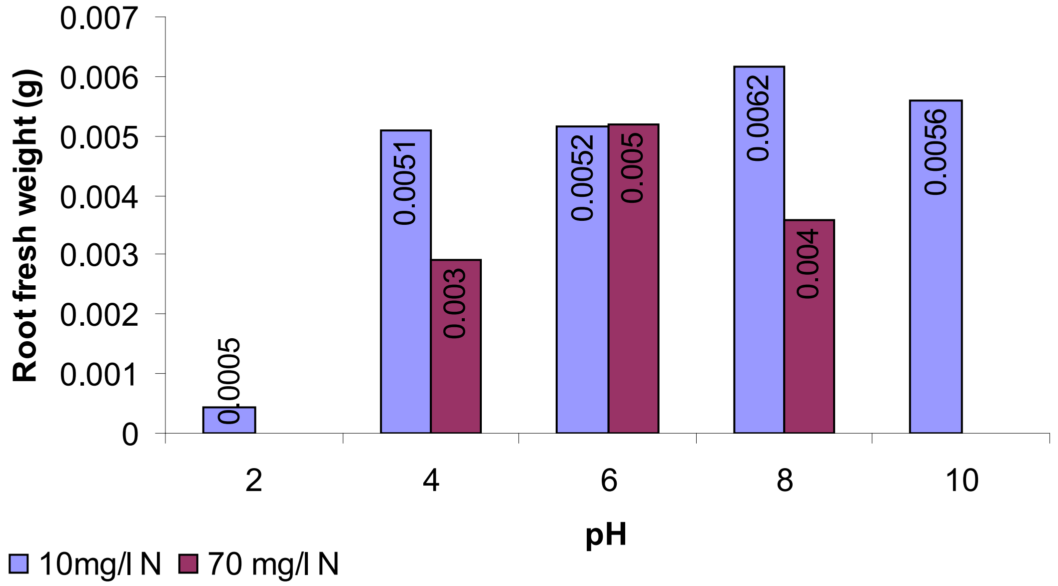


Figure 27: Root fresh weight for Cranberry cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.0033)

Data for cuttings raised in the grit based treatments were different to those from peat/perlite above. For cuttings receiving the 10 mg/l N feed, pH 2 produced lower root fresh weight than pH 4 and 6 and pH 6 had the highest root fresh weight overall. Where the 70 mg/l feed was used, pH 4 produced higher root fresh weight than pH 8. The 10 mg/l N pH 6 treatment was the most favourable for root fresh weight, but there were no further differences in root fresh weight relating to concentration of liquid feed.

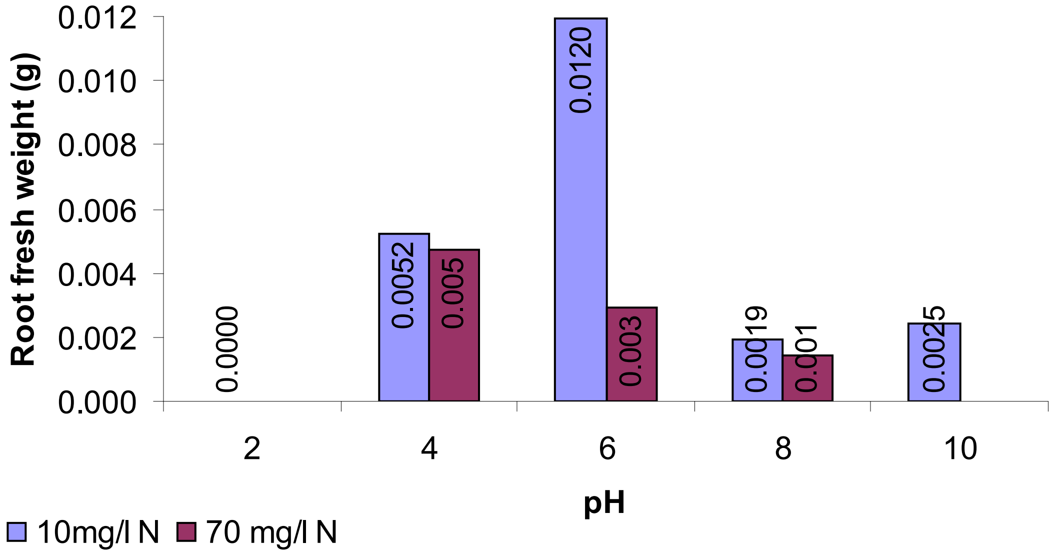


Figure 28: Root fresh weight for Cranberry cuttings rooted in grit (l.s.d. ($P<0.05$) = 0.0033)

Root score

Scores allocated for extent of rooting in peat/perlite reflect the fresh weight data described above. That is, where the 10 mg/l N feed was used, pH 2 resulted in less rooting than the remaining pH treatments and there were no differences relating to pH when the 70 mg/l N feed was used. There were no differences in root score relating to liquid feed concentration.

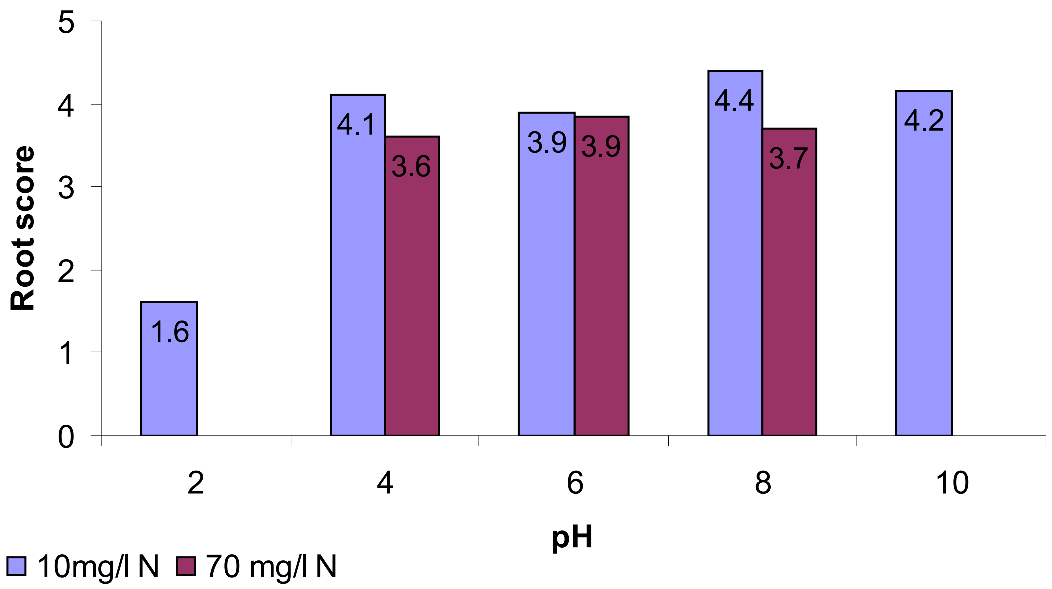


Figure 29: Root score for Cranberry cuttings rooted in peat/perlite (l.s.d. ($P<0.05$) = 1.2)

Root scores for cuttings raised in grit reflect the root weight data. That is, at 10 mg/l N, pH 2 had no rooted cuttings and in fact was scored at 0 which refers to cuttings that have died back without rooting. pH 6 had a higher root score than pH 8 or 10. At 70 mg/l there were no pH differences within the range pH 4-8. The 10 mg/l feed produced higher root score at pH 6 but there was no difference relating to feed at pH 4 or 8.

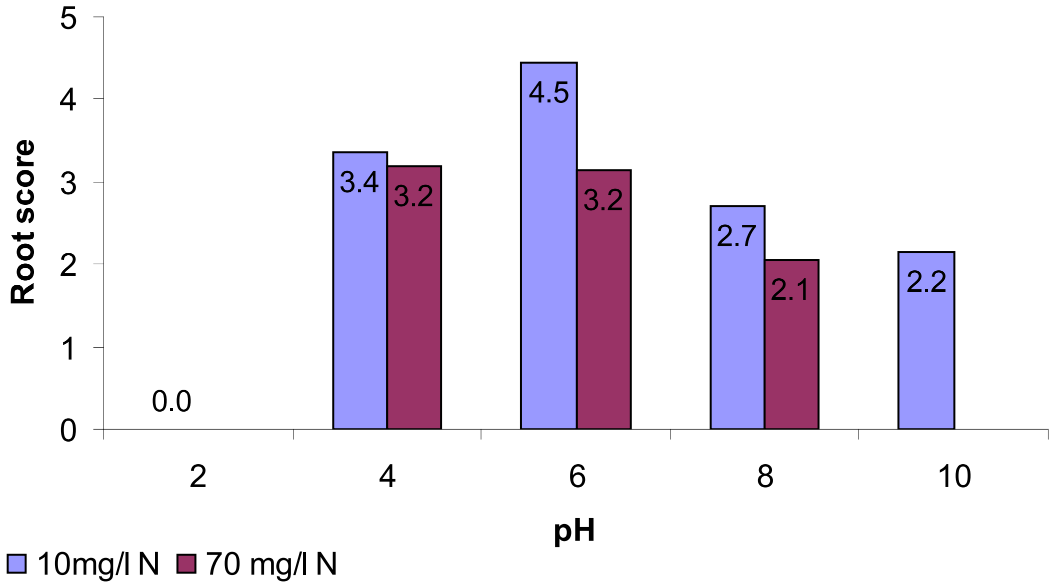


Figure 30: Root score for Cranberry cuttings rooted in grit (l.s.d. ($P<0.05$) = 1.2)

Erica carnea 'Pink Spangles'

Root fresh weight

Where peat/perlite substrates were irrigated with the 10 mg/l N feed, pH 2 and 10 produced the lowest root fresh weight and pH 6 produced the highest with no differences between pH 4 and 8. Irrigation with the 70 mg/l N feed decreased rooting within all the pH treatments tested compared with 10 mg/l N feed, with no differences due to pH.

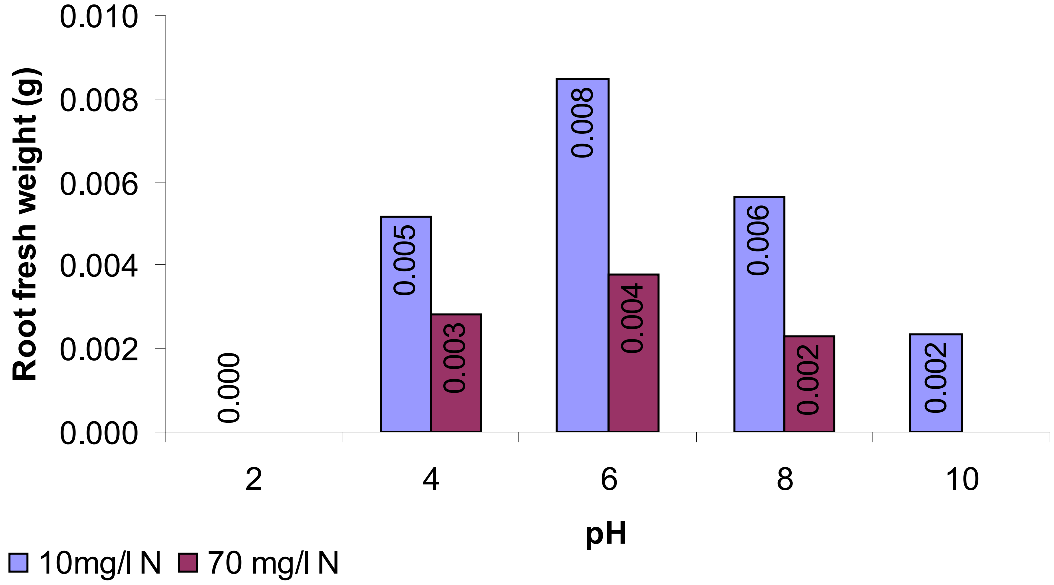


Figure 31: Root fresh weight for *Erica carnea* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.0032)

Cuttings in grit had lower root fresh weight overall than in peat/perlite. The 10 mg/l N pH 4 treatment had the highest root fresh weight with no differences between the remaining treatments.

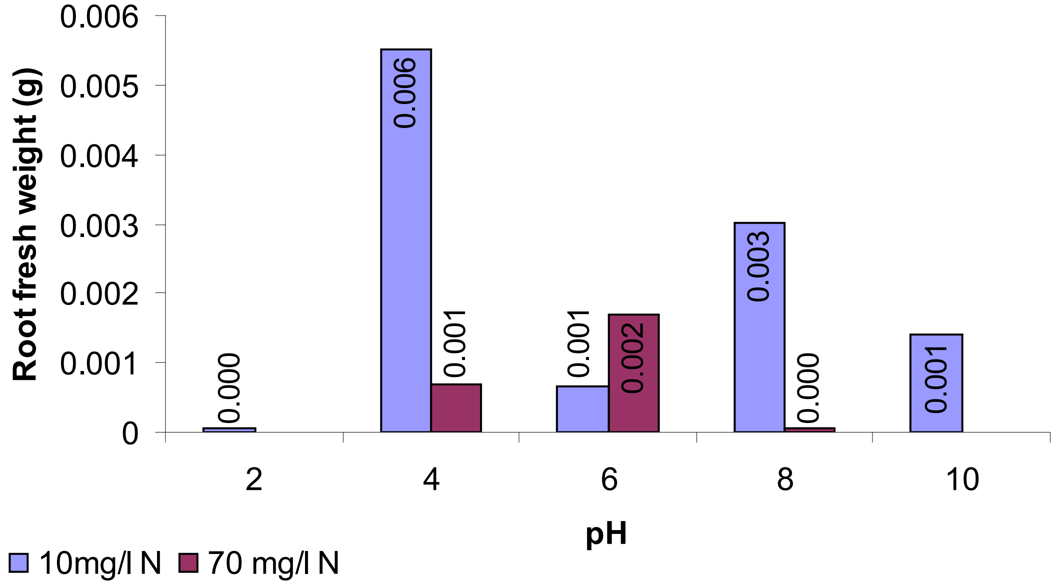


Figure 32: Root fresh weight for *Erica carnea* cuttings rooted in grit (l.s.d. (P<0.05) = 0.0032)

Root score

Root scores in peat/perlite treatments reflect the root fresh weight data. The lowest score resulted from the 10 mg/l N pH 2 treatment followed by pH 10. There were no differences between scores between pH 4 and 8 at 10 mg/l N or between the pH 4 to 8 at 70 mg/l N. Scores were higher from 10 mg/l N than from 70 mg/l N.

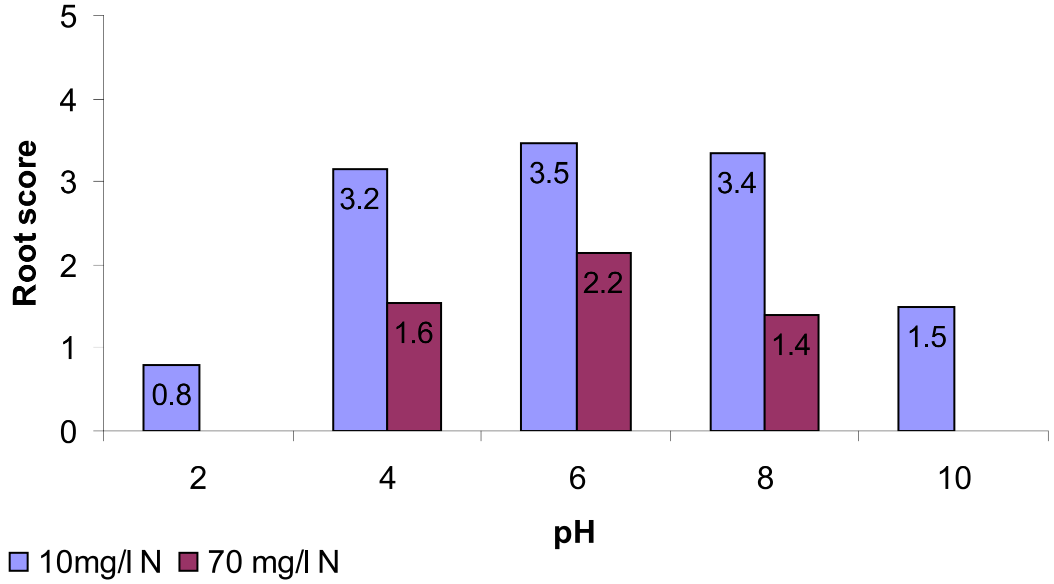


Figure 33: Root score for *Erica carnea* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 1.46)

Root scores in grit treatments reflect root weight data with the 10 mg/l N treatment producing the highest root score and no significant differences between the remaining treatments.

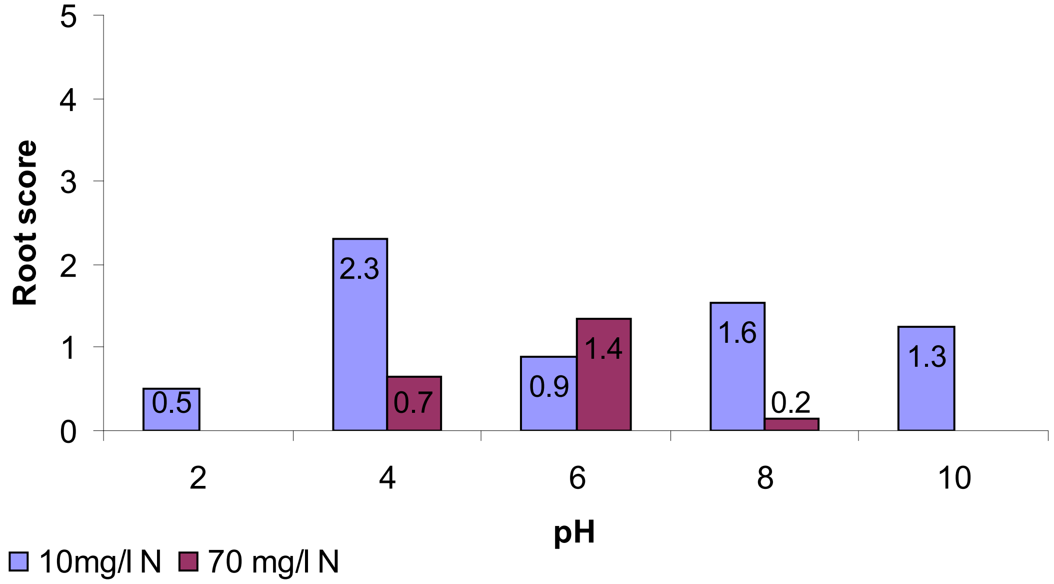


Figure 34: Root score for *Erica carnea* cuttings rooted in grit (l.s.d. (P<0.05) = 1.46)

***Rhododendron* 'Chikor'**

Root fresh weight

Media type significantly influenced root fresh weight and *Rhododendron* preferred the peat/perlite system.

Within the peat/perlite treatment, root fresh weight was greater from the 10 mg/l N feed than from 70 mg/l N within the pH range 4 to 8. There were no significant differences between pH treatments within the pH 4 to 8 range with either concentration of feed. pH 10 significantly reduced root fresh weight compared with pH 4 to 8 and no measurable rooting occurred in the pH 2 treatment.

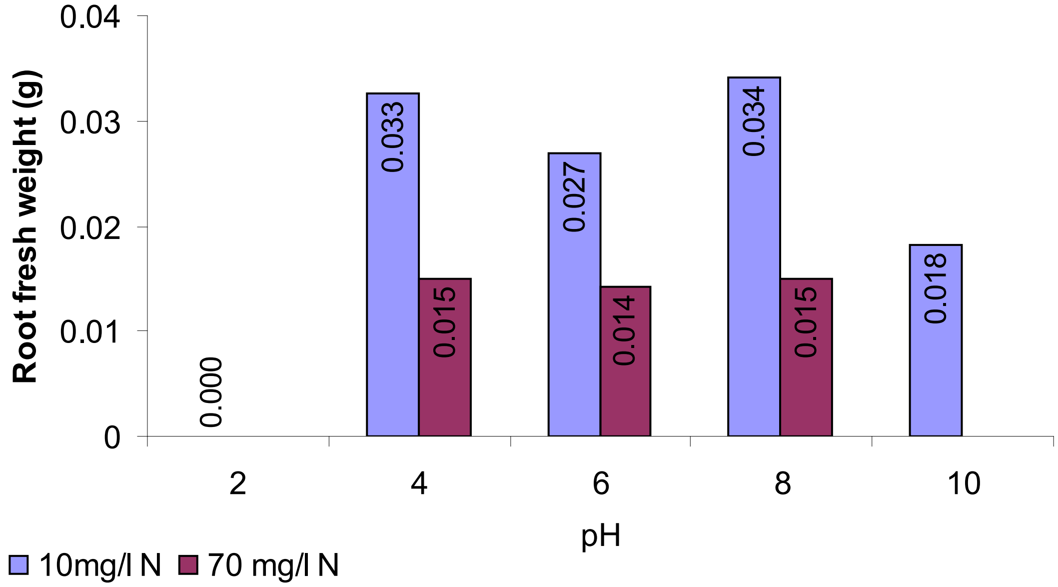


Figure 35: Root fresh weight for *Rhododendron* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.015)

Cuttings rooted in grit responded differently to the pH adjusted nutrient solutions when compared with those rooted in peat/perlite. Whilst there was significantly more root in the lower than the higher feed treatment at pH 4, feed concentration did not influence rooting within the pH 6 and 8 treatments. As with the peat/perlite treatments, there was no detectable rooting at pH 2.

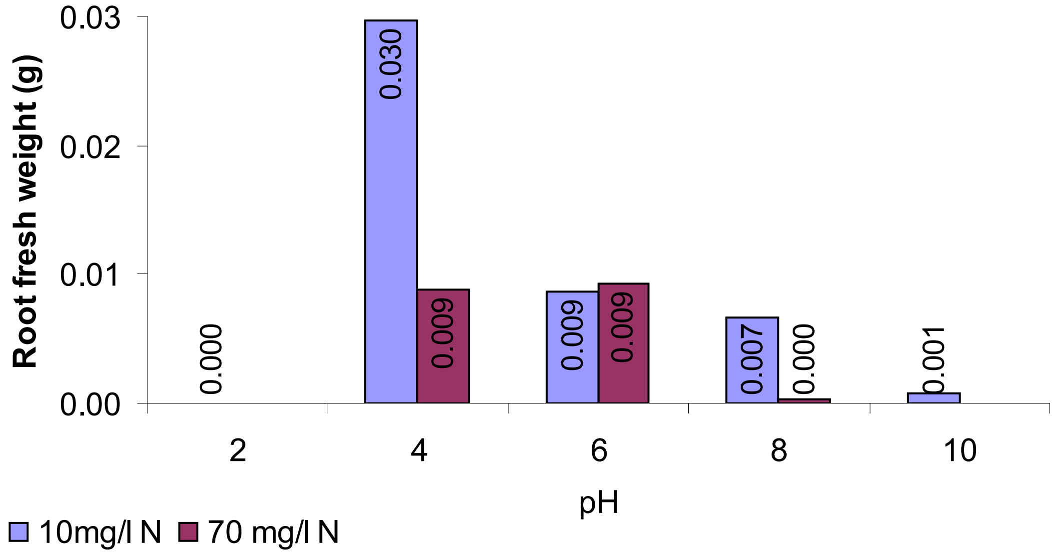


Figure 36: Root fresh weight for *Rhododendron* cuttings rooted in grit (l.s.d. (P<0.05) = 0.015)

Root scores

Average root scores for *Rhododendron* rooted in peat/perlite reflect the fresh weight data described above, with higher scores for the lower nutrient concentration (10 mg/l N) and the poorest rooting at pH 2. There was no difference in root scores between the pH 4-10 treatments.

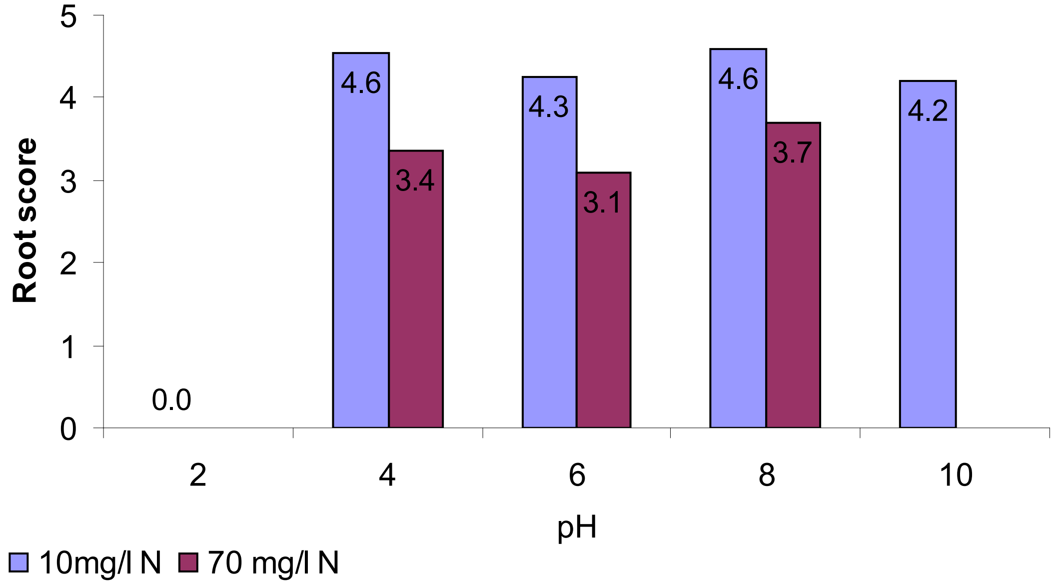


Figure 37: Root score for *Rhododendron* cuttings rooted in peat/perlite (l.s.d. (P<0.05) = 0.83)

Root scores in the grit treatments were lower overall than those in the peat/perlite treatments. The pH 4 treatment combined with low feed produced the highest root score. Cuttings at pH 2 in grit died back before any root development appeared.

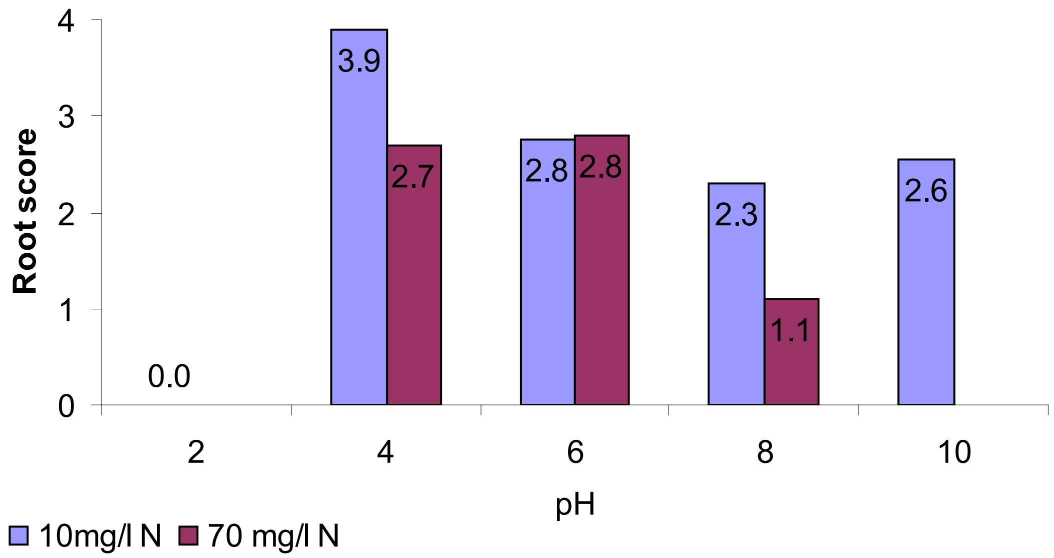


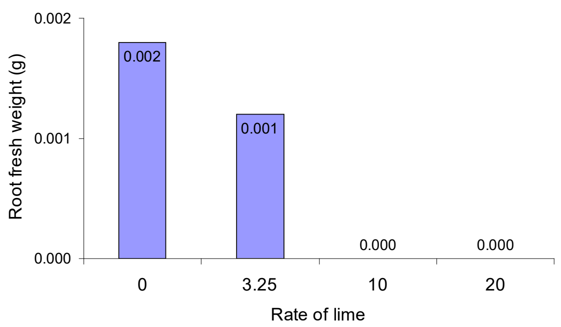
Figure 38: Root score for *Rhododendron* cuttings rooted in grit (l.s.d. (P<0.05) = 0.83

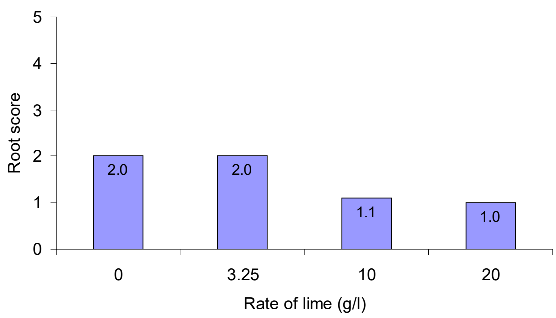
Experiments with limed peat/perlite substrates irrigated with tap water

These experiments were not replicated and were therefore not formally analysed.

Blueberry (*Vaccinium corymbosum* 'Bluecrop')

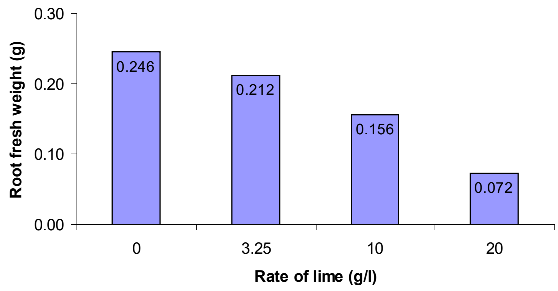
Both root fresh weight and root score data suggest that blueberry rooting was better with either no lime or lime at 3.25 g/l (i.e. pH 4.6 to 6.0) compared with higher rates of lime.

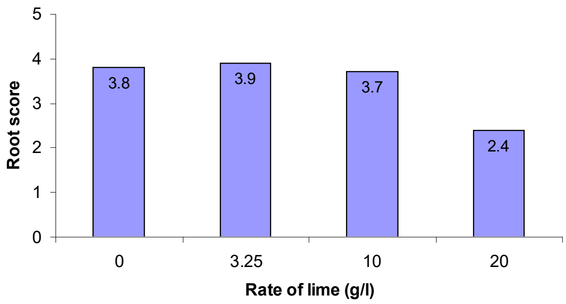




***Clematis* 'Dr Ruppel'**

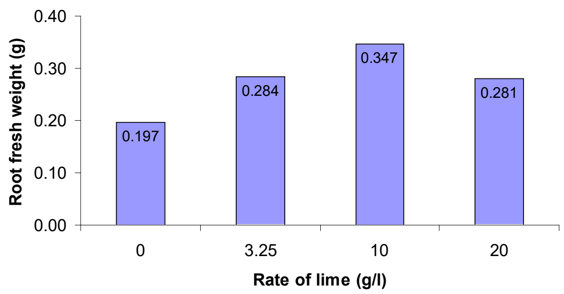
Gutters set up with the limed peat/perlite treatments were less severely affected by *botrytis* than those in the main experiment. Results from these treatments indicate a decrease in root fresh weight as rate of lime increased. Root score data was less sensitive with little difference between 0 and 10 g/l (pH 4.6 to 6.2) and a decrease in score at the 20 g/l (pH 6.5) rate of lime.

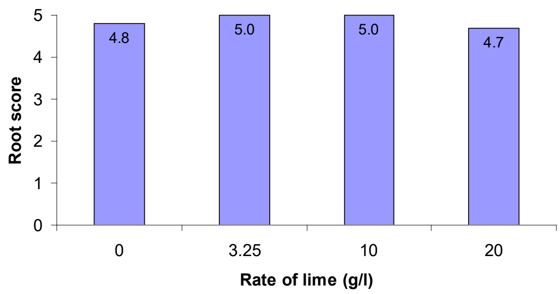




Rosa Red Bells (Poulred)

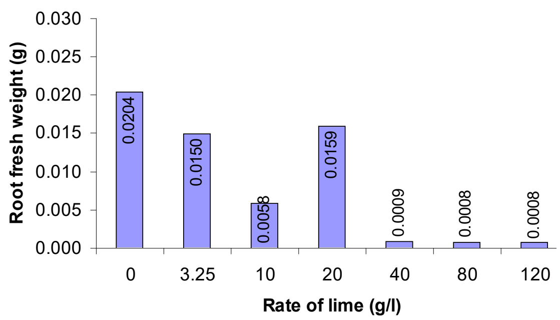
Root fresh weight data suggests a preference for the lime rate of 10 g/l which was equivalent to pH 6.2 by the end of the experiment although root weight was similar to this from both the 3.25 and 20 g/l lime treatments. Root scores were similar for all rates of lime tested.

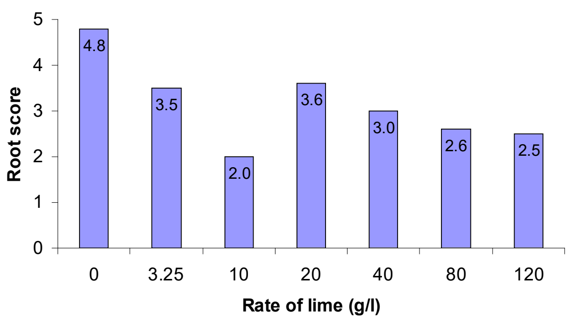




***Calluna vulgaris* 'Allegro'**

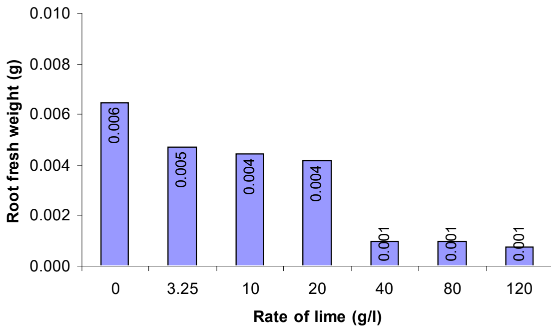
Increasing the rate of lime added to peat/perlite decreased root fresh weight and root score overall with some discrepancy at the 10 g/l rate of lime where rooting appeared to drop significantly but then increase again at 20 g/l.

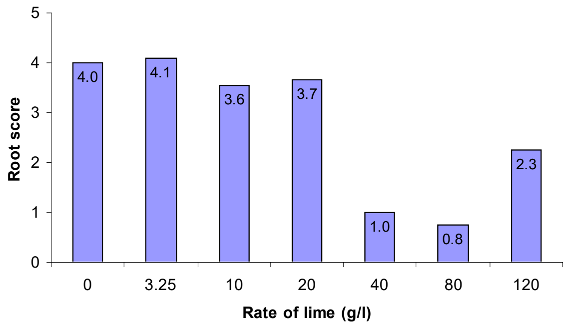




Cranberry (Vaccinium oxycoccos)

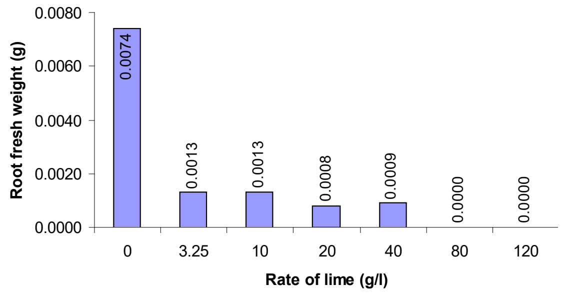
Root fresh weights suggest a slight preference for the unlimed (pH 4.6) peat/perlite substrate but there is little separation between treatments within the 0 to 20 g/l lime range (pH 4.6 to 6.6). Rooting was apparently impeded at higher rates of lime but since pH stabilised at these rates these results may be due to the increases in Ca and Mg ions and/or substrate conductivity.

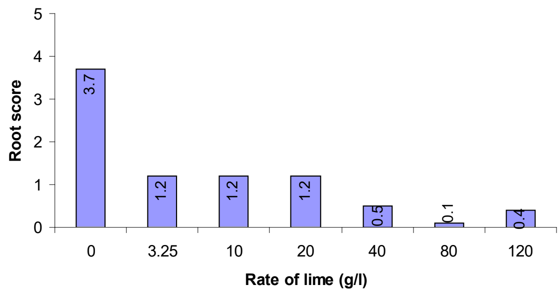




Erica carnea *'Pink Spangles'*

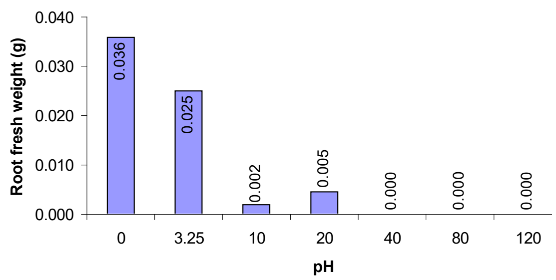
Rooting in the unlimed peat/perlite substrate (pH 4.6) was best when no lime was added.

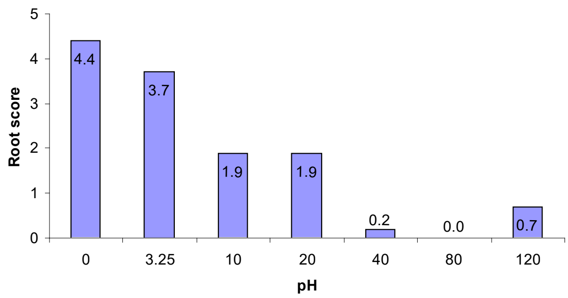




Rhododendron **'Chikor'**

Higher rate of lime decreased both root fresh weight and root score with unlimed peat/perlite (approx pH 4.6) producing the highest root weight and score overall.





DISCUSSION

The following discussion considers the October 2007 experiments initially which covered a wider set of treatments. The May and July 2008 experiments, which repeated the same set of treatments for different species, are then discussed together.

Experiments aimed to consolidate previous work by examining if the smaller than expected responses to pH in year 1 and 2 experiments may have been related to other factors limiting rooting in the cuttings studied, and also to further extend species studied. The three substrates studied in the October 2007 experiments had different aeration properties as well as different buffering potential. Mineral analysis results illustrated how buffering in peat/perlite apparently limited the ability to raise substrate pH when target treatment level was above pH 6, although pH of the nutrient solution applied was maintained at the target pHs set. If lack of aeration was restricting rooting, which had been a concern in sand-based treatments previously, cuttings in perlite gutters may have performed the best. In practise, the highest rooting scores were achieved in the peat/perlite and grit rather than in the perlite. However the ability to examine the direct effects of pH alone were limited in peat by the buffering already described which apparently limited treatments at the higher end of the pH range studied.

Studies with different nutrient concentrations in the pH adjusted liquid feed aimed to examine if the apparent 'stalling' in root development seen in earlier experiments was due to a lack of nutrition. The higher nutrient concentration (i.e. 70 mg/l N with other elements in the same proportions to this as used in the 10 mg/l N feed previously) however generally gave poorer rather than better rooting. The higher concentration feed was designed not to be excessive and in fact was based on the concentration of nutrients expected in general purpose commercial peat based rooting media but it would appear that this level of nutrient was in excess of cutting requirements. This suggests that lack of nutrient may not have been limiting rooting, and therefore potential to respond to pH, in previous experiments. The higher nutrient concentration treatments were also supplemented with micronutrients and hence lack of micronutrients should not have been the reason for the lack of response to pH.

Transferring partially rooted cuttings to treatments was designed to examine if earlier and later stages of adventitious rooting have different sensitivities to pH. Where pH had some effect on rooting, the transferred cuttings had a higher root score those direct struck. This suggests that the initial stages of rooting had been limited by pH where the pH had caused any effect since the transferred cuttings would have avoided these effects until transferred into treatments. For the pH causing the greatest effect on rooting (pH 2), transferred cuttings has less rooting than those transferred to pH 4 and 6 which produced the best rooting. This suggests that the later stages of adventitious rooting had also responded to pH. Hence the lack of treatment effect so far does not seem to be related to changes in pH sensitivity during the stages of rooting covered in this work. Extending the pH range was effective at generating a greater response to pH than had been previously seen within the range pH 4 to 8. However differences within the range pH 4 to 8 remained small considering the expected preferences for ericaceous subjects in particular. The two heather species tested had slightly different responses to pH treatments; *Calluna vulgaris* rooting was more severely affected by pH 8 and 10 than rooting of *Erica carnea*. The extent of rooting in *E.carnea* at pH 10 was surprising although the root architecture was apparently influenced by this extreme treatment.

Rooting of *E.carnea* was not influenced by change in peat/perlite pH when altered with lime at rates in the range 0 to 8.25 g/l, however there was less rooting of *C.vulgaris* at the highest rate of lime applied. This reflects the different response to pH observed in the main experiments for these species. However, in these treatments, the effects of pH in the root environment are not separated from the effects of lime on concentration of mineral elements such as calcium and magnesium. Hence whilst trends might be closer to expected preferences, they contrast to the main experiments where the effects of pH were better separated from the effects of concentration of nutrient elements.

Since the October 2007 experiments had been carried out unreplicated, similar experiments were carried out in May and July 2008 to verify results with replicated work which would also take place under different environmental conditions and which provided the opportunity to widen the species range tested. These later experiments were restricted to peat/perlite and grit substrates which produced the best rooting in the October 2007 experiments.

Experiments in May examined Blueberry, *Clematis* and Rose which were thought to prefer acidic, wider ranging and more basic pH respectively. *Botrytis* infection restricted the data available from these experiments with numbers of affected *Clematis* cuttings too high for data to be suitable for presentation. Blueberry also suffered from some botrytis infection whilst Rose was apparently not infected which may in part be due to its rapid rooting and vigorous growth. Root growth of Rose and Blueberry was significantly poorer in the pH 2 treatment. However the pH 2 treatment also had significantly higher conductivity than the pH 4-8 treatments. This increase was related to an increase in concentration of several nutrient ions including sulphur which would have originated from the sulphuric acid used to lower liquid feed pH to the required level as well as several other ions that could not be explained simply by the addition of sulphuric acid alone. It seems possible therefore that the lowest pH treatment may have dissolved impurities out of the substrate that contributed to the increase in conductivity noted. Since the resulting conductivity of the pH 2 was higher than the average conductivity of the higher (70 mg/l N) nutrient feed treatment, it is possible that the increase in conductivity/mineral nutrient concentration had limited rooting as well as / instead of the low pH itself. Higher levels of pH had no further consistent influence over the rooting of Rose or Blueberry.

The heather species tested in July 2008 experiments produced comparable trends to those found in the unreplicated October 2007 experiments. Rooting scores were lower overall in the latter experiments which probably relates to the shorter length of time in propagation as well as the incidence of disease. However as with the October experiments, there was less/no rooting at pH 2 and also some restriction on rooting at pH 8 and 10. Slight preferences for pH 4 and 6 were observed but overall the differences within the pH 4-8 range were small, reflecting results found in experiments in year 1 and 2. As described previously, the impact of pH 2 on rooting may at least in part be associated with the increased concentration of nutrient ions and hence conductivity of the peat/perlite substrate in these treatments. Peat/perlite irrigated at pH 10 also inhibited rooting to some extent, particularly for *Calluna vulgaris*, and in this case the mineral nutrient status of the substrate was comparable with that from the pH 4-6 treatments associated with the best rooting. The lower concentration nutrient solution produced more rooting of both species of heather than the higher concentration and the peat/perlite medium was better for heather rooting than the grit.

As with the heathers, *Rhododendron* rooted better in peat/perlite than in grit and in the 10 mg/l N feed than in the 70 mg/l N feed. There was no response to pH within the range pH 4-8 for *Rhododendron* in peat/perlite although rooting was suppressed at pH 2. In grit, pH 4 appeared to produce more rooting than the other treatments but overall cuttings in grit were not rooting as well as they were in peat/perlite which may limit the value of this response. Cranberry also rooted better overall in peat/perlite and with the low nutrient concentration. A low response to pH within the range pH 4-8 was also found with this species, with rooting severely limited or cuttings dying back at pH 2.

Hence these experiments have indicated that factors such as substrate type and nutrient concentration can be expected to influence extent of rooting. Response to pH treatments within the range 4-8 remains smaller than anticipated. Extending pH treatments has generated greater response with pH 2 in particular inhibiting rooting in all species. However mineral analyses have indicated that pH 2 was also associated with a significant increase in conductivity of the peat/perlite substrate due to an increase in concentration of a number of mineral nutrients and hence the impact of this treatment may not have been due to the direct effects of pH alone. For some species, the pH 10 treatment also limited rooting, and in this case there is less evidence for conflict with change in mineral nutrient status. At the two extremes of pH tested therefore it has been possible to generate a response of rooting to pH although responses remain limited compared with expectations and these extreme treatments are unlikely to be repeated in a commercial situation.

As in the October 2007 work, parallel experiments were set up in the May and July 2008 experiments to examine how adding lime to increase the pH of peat/perlite substrates might influence rooting. These treatments increased concentration Ca and Mg in the substrate as would be expected but this was accompanied by a general increase in a range of mineral ions presumably originating from impurities within the dolomitic lime used which increased conductivity as well as pH. Hence whilst changing pH of peat/perlite with lime gave a potentially better buffered system, it did not separate the effects of pH from those of nutrition and the differences in conductivity of substrate between the lowest and highest rate of lime tested was equivalent to that associated with the two nutrient concentration treatments which consistently reduced rooting when at the higher of the two levels tested. In general the species tested rooted better with either no lime or rates at the lower end of the range tested (i.e. 0 – 3.25 g/l or pH 4.6 – 5.9). Rose however preferred the 10 g/l rate of lime (giving a substrate pH of 6.2) to lower rates tested.

Experiments throughout this project have been designed to separate any direct effects of pH from the changes in availability of nutrients that accompany changes in pH. Where pH treatment had the greatest impact on rooting, this has been accompanied by other changes in mineral nutrient status, which were generally an increased concentration of nutrient ions. Since these experiments have also indicated how moderate increases in nutrient concentration have been detrimental to rooting it is likely that the change in mineral status accompanied by both the pH 2 treatment applied to substrates in the main experiment and the high lime treatments in observational work also had an impact on rooting. Lack of response may therefore suggest that experiments have been successful in separating these effects and that it is the impact of pH on nutrition that is the critical factor. It is not clear if these results are representative of the rooting phase alone or if the pH related differences seen in plant growth are linked to differences in mineral nutrition, and possibly on microbial activity (e.g. nitrification) rather than the direct effect of concentration of hydrogen ions in solution.

CONCLUSIONS

Response to rooting within the pH 4 to 8 range was limited overall where the impact of pH on nutrition was kept to a minimum.

Cuttings struck in the pH 2 treatment consistently had the poorest rooting, often dying back before final assessments were made. Mineral analysis data indicates this may be due at least in part to a marked increase in nutrient ions and hence conductivity in this treatment. It is suggested that this increase in conductivity was a result of the low pH dissolving components of the grit or peat/perlite substrate which in turn created an osmotic stress limiting / preventing root growth and often cutting survival. Stress resulting from the accumulation of toxic levels of specific ions (e.g. Na) in the cutting is also possible in such situations of high substrate conductivity.

pH 10 limited rooting to a lesser extent than pH 2 and it also had comparable nutrient status to other pH treatments combined with the 10 mg/l N feed. This further points to the negative impact of pH 2 on rooting being related to the general increase in conductivity for this treatment.

Rooting of cranberry, *Calluna vulgaris* and *Erica carnea* demonstrated some preference for pH within the range 4-6. Other ericaceous subjects such as *Rhododendron* and Blueberry had comparable rooting across the pH range 4 to 8.

Rooting of a range of species was better at a lower rate of nutrition (i.e. N at 10 rather than 70 mg/l N with other elements in proportion to N) and this lower rate was suitable even for the most vigorous species tested (i.e. *Rosa* Red Belle (Poulred)).

Most of the species tested rooted better in peat/perlite treatments than in grit but were also apparently better buffered against change in pH in peat/perlite treatments and hence potentially exposed to less extreme differences in pH than the grit treatments.

Where pH was manipulated using different rates of lime in a peat/perlite substrate, greater differences in rooting occurred. However concentration of Ca and Mg as well as a range of other mineral elements and therefore also conductivity increased with rate of lime making it difficult to separate the effects of nutrition from the direct effects of pH (or concentration of hydrogen ions).

Species preferring lower rates of lime (0 to 3.25 g/l) included *Rhododendron*, *Calluna vulgaris*, *Erica carnea* and Blueberry. *Clematis* and Cranberry rooted well at between 0 and 20 g/l lime and Rose had a preference for slightly higher pH, rooting best at the 10 g/l rate of lime.

Overall, investigations into the effects of pH alone on rooting have been extensive with considerable care taken to ensure methodology was appropriate to meet experimental aims; including ensuring that rooting was not limited by other factors that could mask responses to pH. In general a consistent pattern of results have emerged which suggest that pH alone had little effect on adventitious rooting. When pH interacts with nutritional factors however, greater and more predictable responses to pH have emerged. In commercial systems the interaction between pH and nutrition is likely to remain unless growers use more inert growing systems and hence will still need to account for pH because of its interaction with other factors. Results from this trial however indicate that where errors with acid dosing systems occur there is potential to impact substrate conductivity as well as pH with potential for severe osmotic stress if left unchecked.

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Appendix I – Photographic illustration of rooting scores

Calluna vulgaris

Root score: 0 1 3 4 5

Erica carnea

Root score: 0 1 3 4 5

Cranberry

Root score: 0 1 3 4 5

Rhododendron

Root score:
0 1 3 4 5

Rose


Root score:

0 1 3 4 5

Clematis


Root score:

0 1 2 3 4 5

Appendix 2 – Photographs of cuttings at final assessment

Calluna vulgaris October 2007 - perlite

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

Calluna vulgaris October 2007 - perlite

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Calluna vulgaris October 2007 - grit

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

Calluna vulgaris October 2007- grit

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Calluna vulgaris October 2007– peat/perlite

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

Calluna vulgaris October 2007– peat/perlite

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Erica carnea October 2007 - perlite

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

Erica carnea October 2007 - perlite

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Erica carnea October 2007 - grit

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

Erica carnea October 2007 - grit

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Erica carnea October 2007 – peat/perlite

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

Erica carnea October 2007 – peat/perlite

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Blueberry May 2008 - Grit

Rep 1 | Rep 2

pH2 10 mg/l N

pH4 10 mg/l N

pH6 10 mg/l N

pH8 10 mg/l N

pH10 10 mg/l N

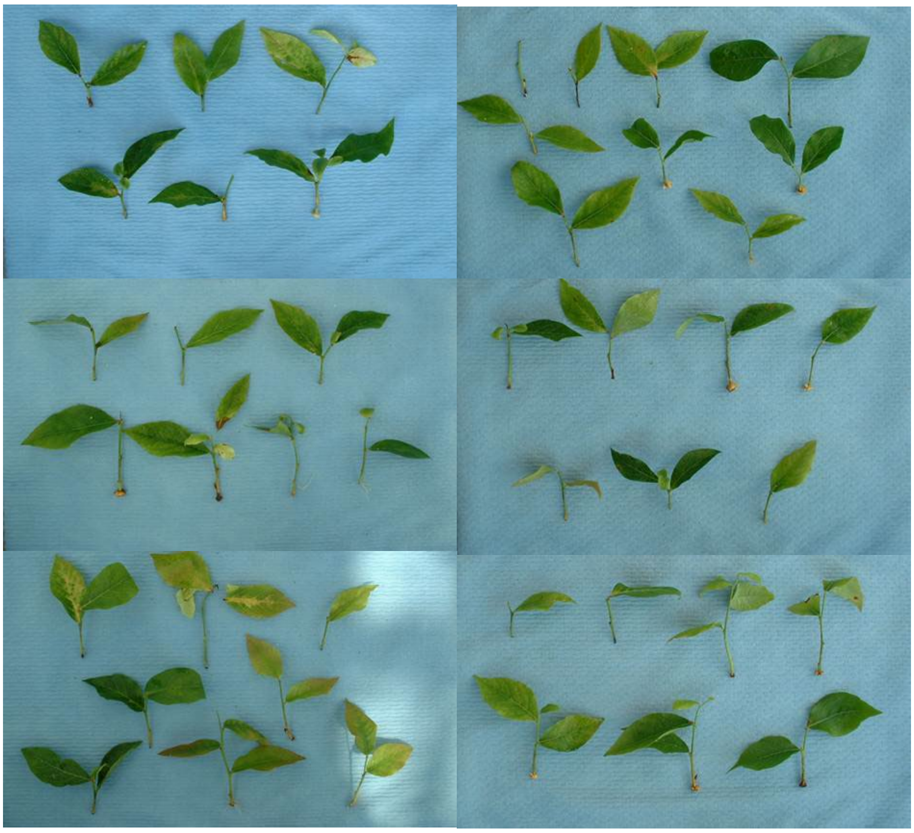
Blueberry May 2008 - Grit

Rep 1 | Rep 2

pH4 70 mg/l N

pH6 70 mg/l N

pH8 70 mg/l N



Blueberry May 2008 - peat/perlite

Rep 1 | Rep 2

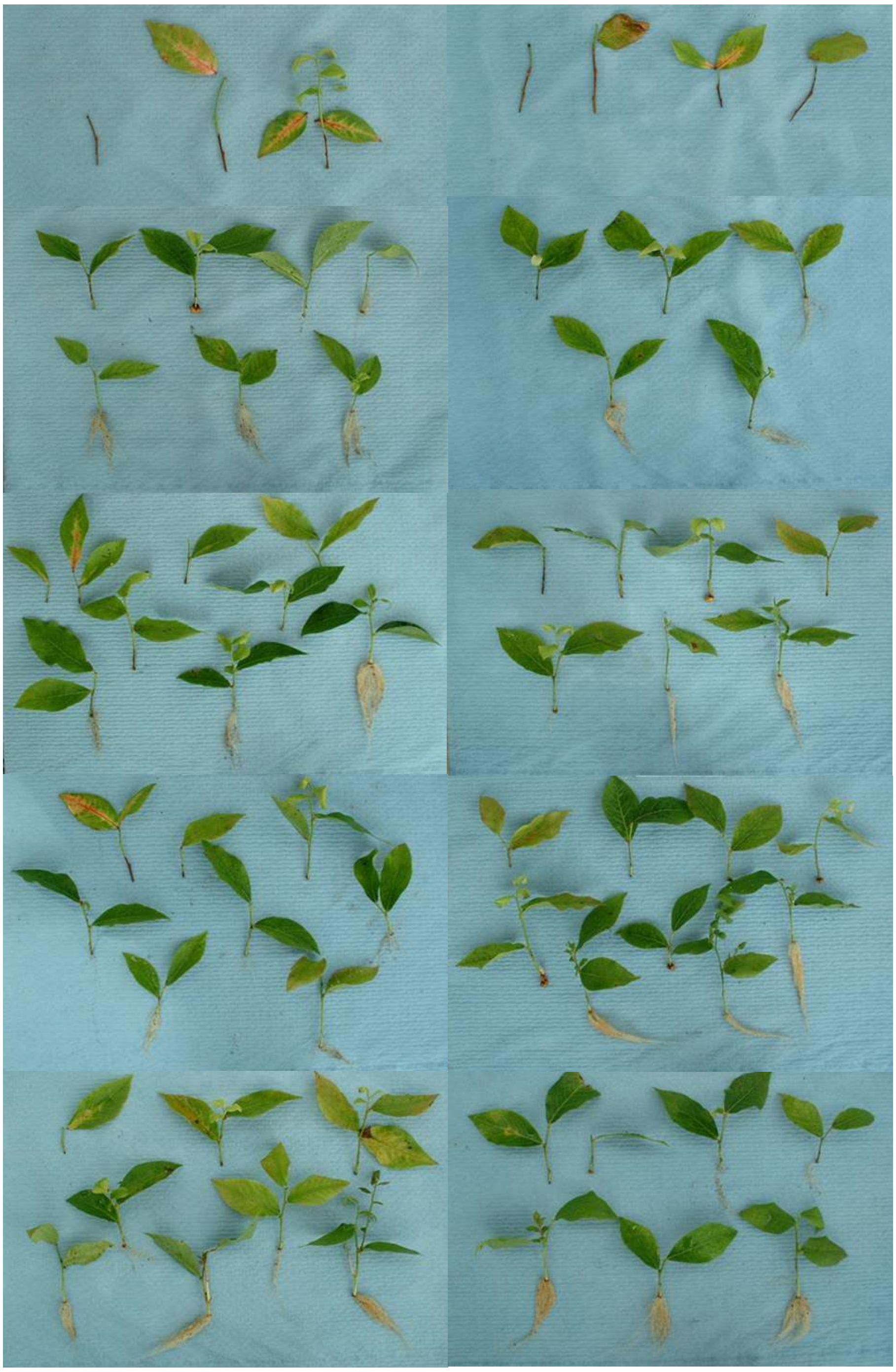
pH2 10 mg/l

pH4 10 mg/l

pH6 10 mg/l

pH8 10 mg/l

pH10 10 mg/l



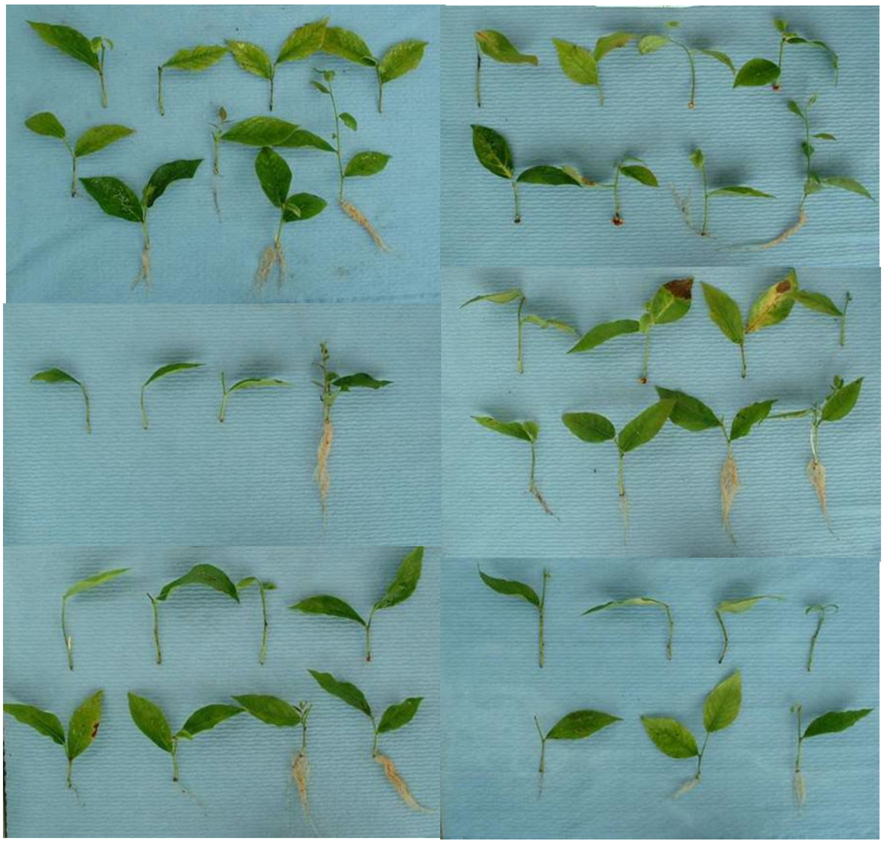
Blueberry May 2008 - peat/perlite

Rep 1 Rep 2

pH4
70 mg/l

pH6
70 mg/l

pH8
70 mg/l



Blueberry May 2008 - limed peat/perlite

0 lime

3.25g/l lime

10g/l lime

20g/l lime

Clematis May 2008 - grit

Rep 1 Rep 2

pH4
10 mg/l

pH6
10 mg/l

pH8
10 mg/l

pH10
10 mg/l

Clematis May 2008 - grit

Rep 1 Rep 2

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Clematis May 2008 - peat/perlite

Rep 1 | Rep 2

pH4 10 mg/l

pH6 10 mg/l

pH8 10 mg/l

pH10 10 mg/l

Clematis May 2008 - peat/perlite

Rep 1 Rep 2

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Clematis May 2008 - limed peat/perlite

0 lime

3.25g/l lime

10g/l lime

20g/l lime

Rose May 2008 - grit

Rep 1 Rep 2

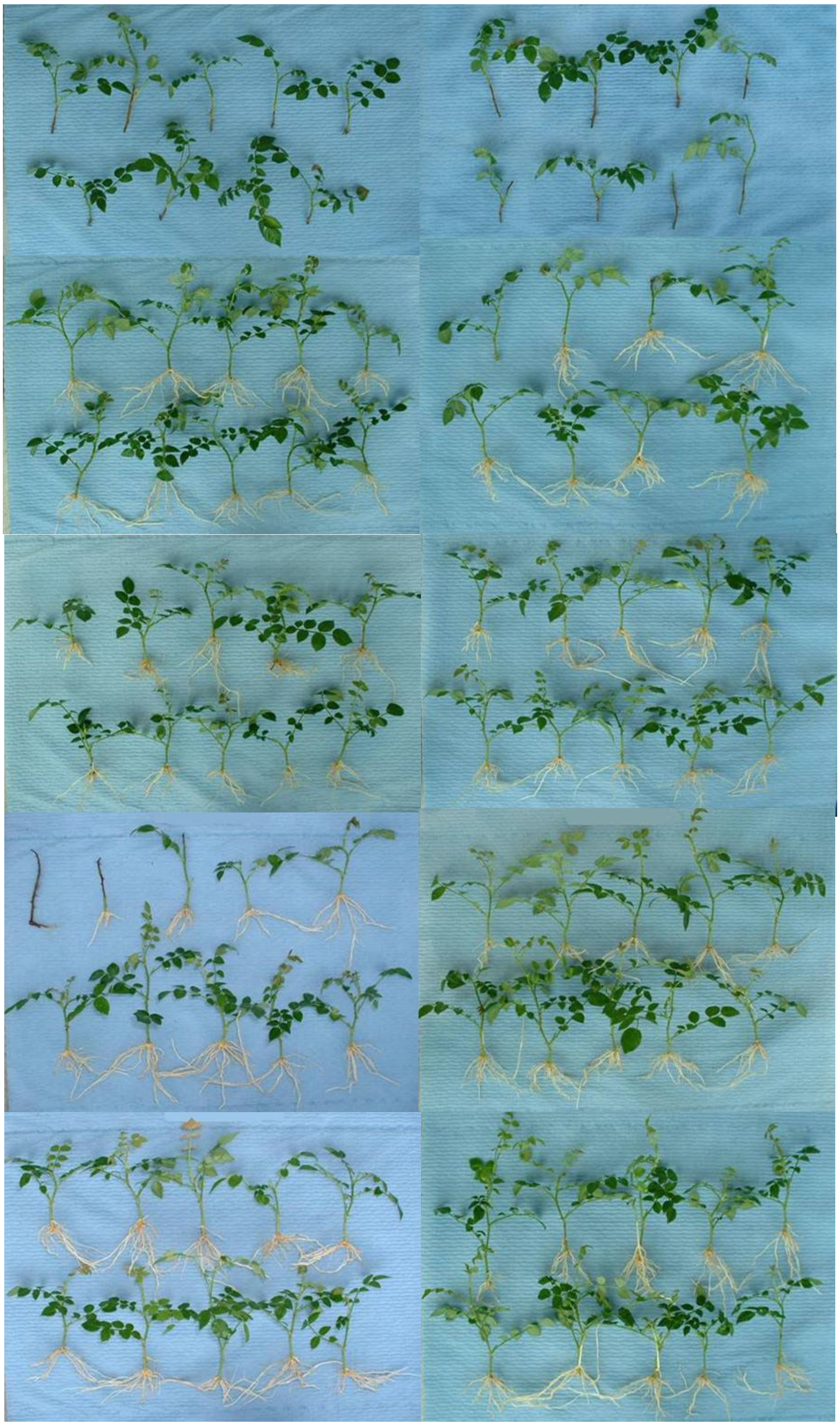
pH2
10 mg/l

pH4
10 mg/l

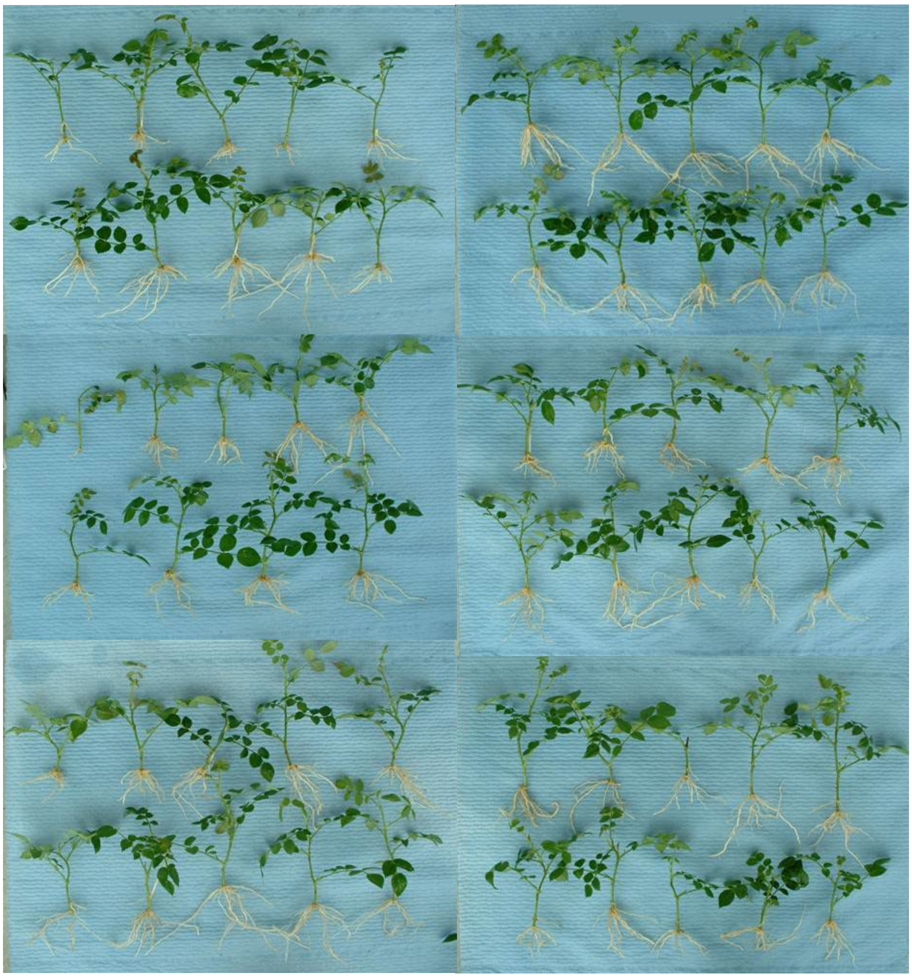
pH6
10 mg/l

pH8
10 mg/l

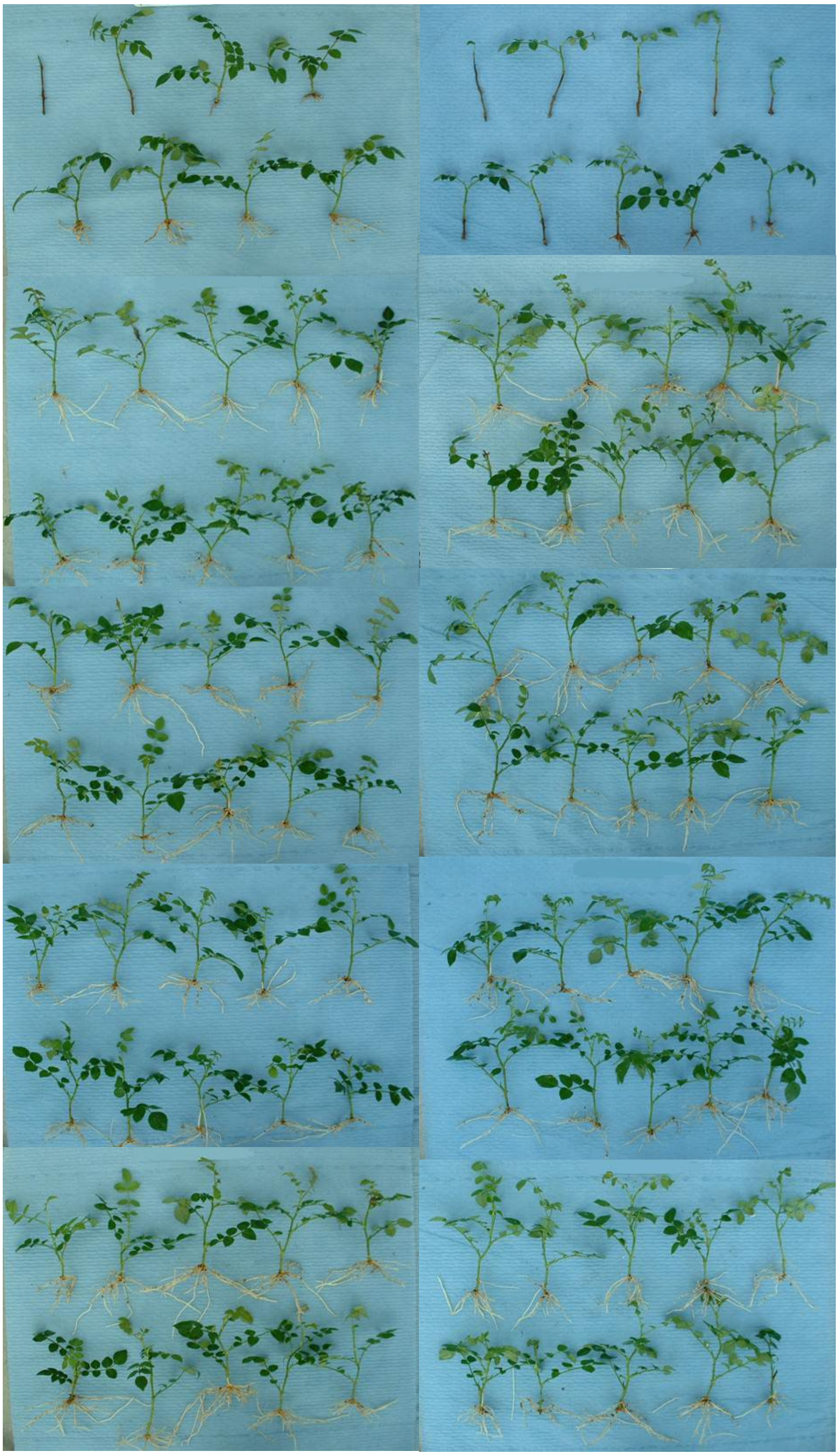
pH10
10 mg/l



Rose May 2008 - grit



Rose May 2008 - peat/perlite



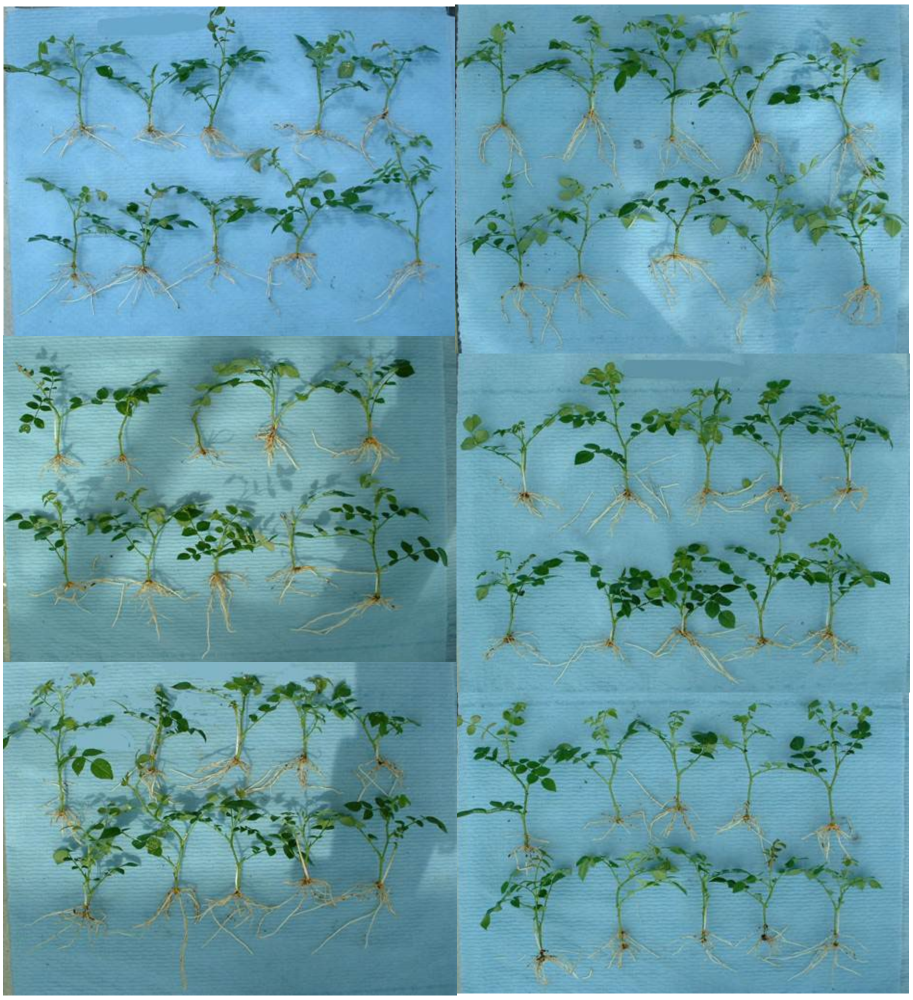
Rose May 2008 - peat/perlite

Rep 1 Rep 2

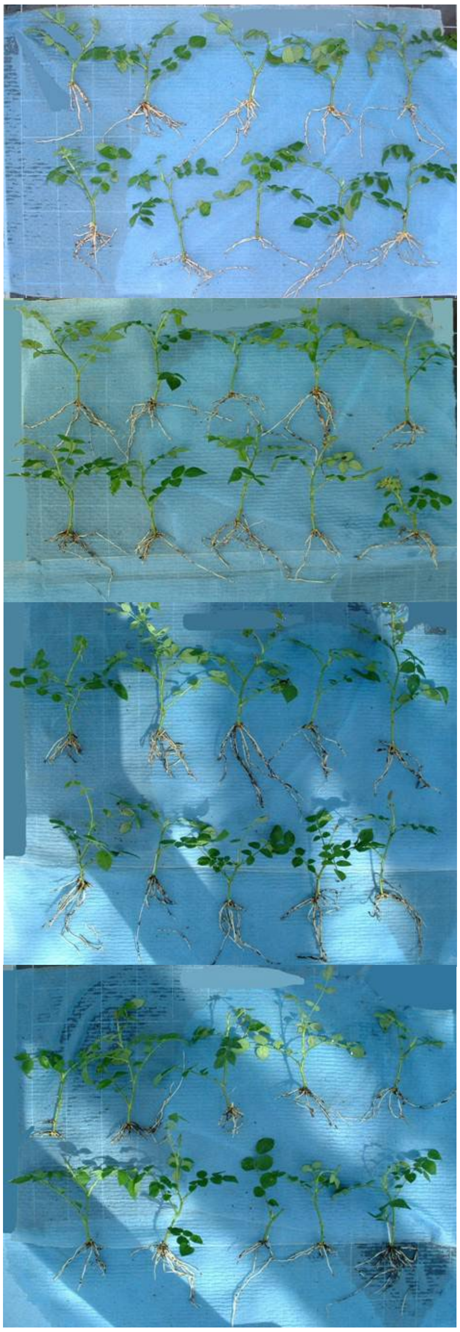
pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N



Rose May 2008 - limed peat/perlite



0 lime

3.25g/l lime

10g/l lime

20g/l lime

Calluna vulgaris July 2008 - grit

Rep 1 Rep 2

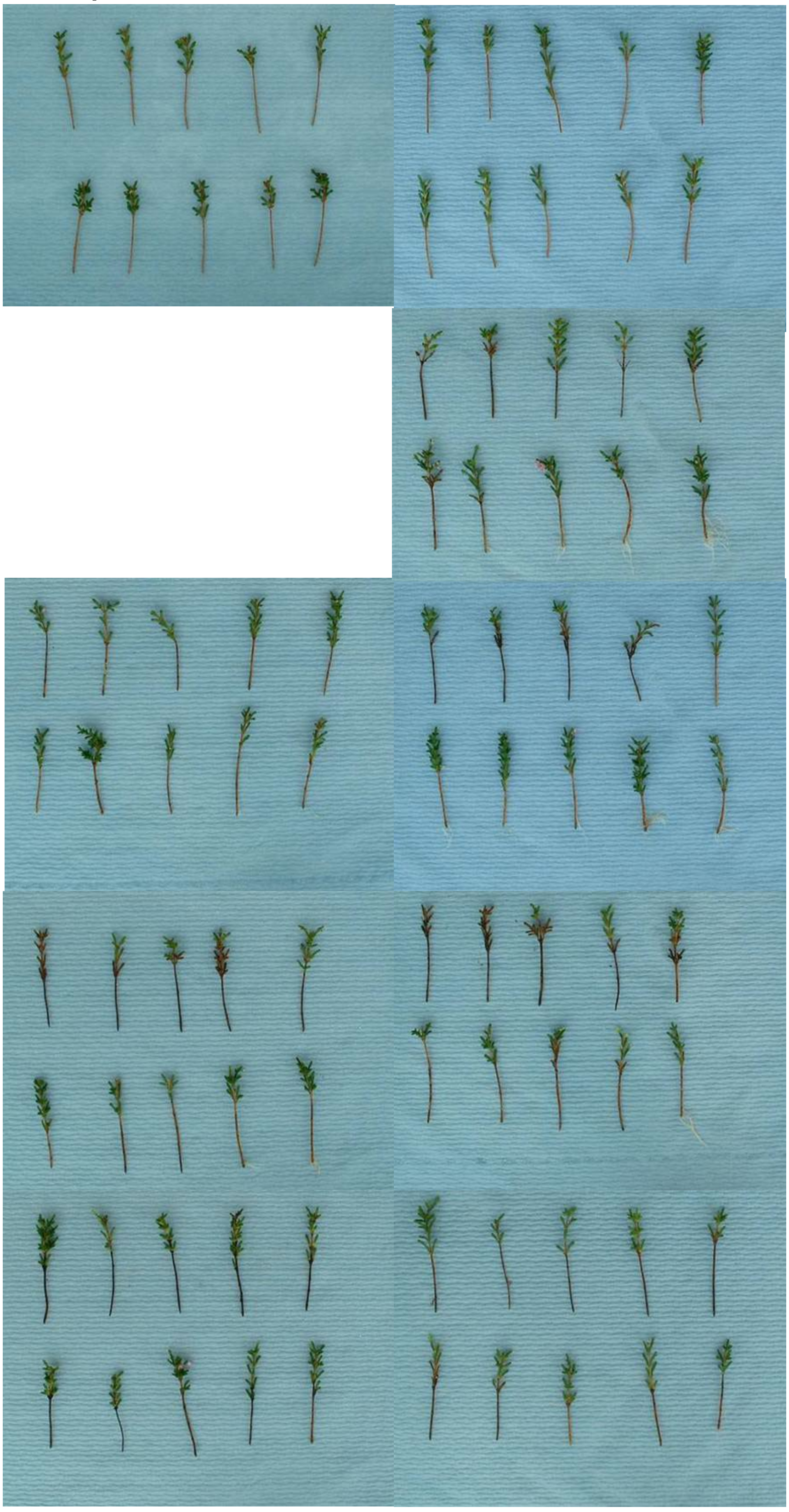
pH2
10 mg/l

pH4
10 mg/l

pH6
10 mg/l

pH8
10 mg/l

pH10
10 mg/l



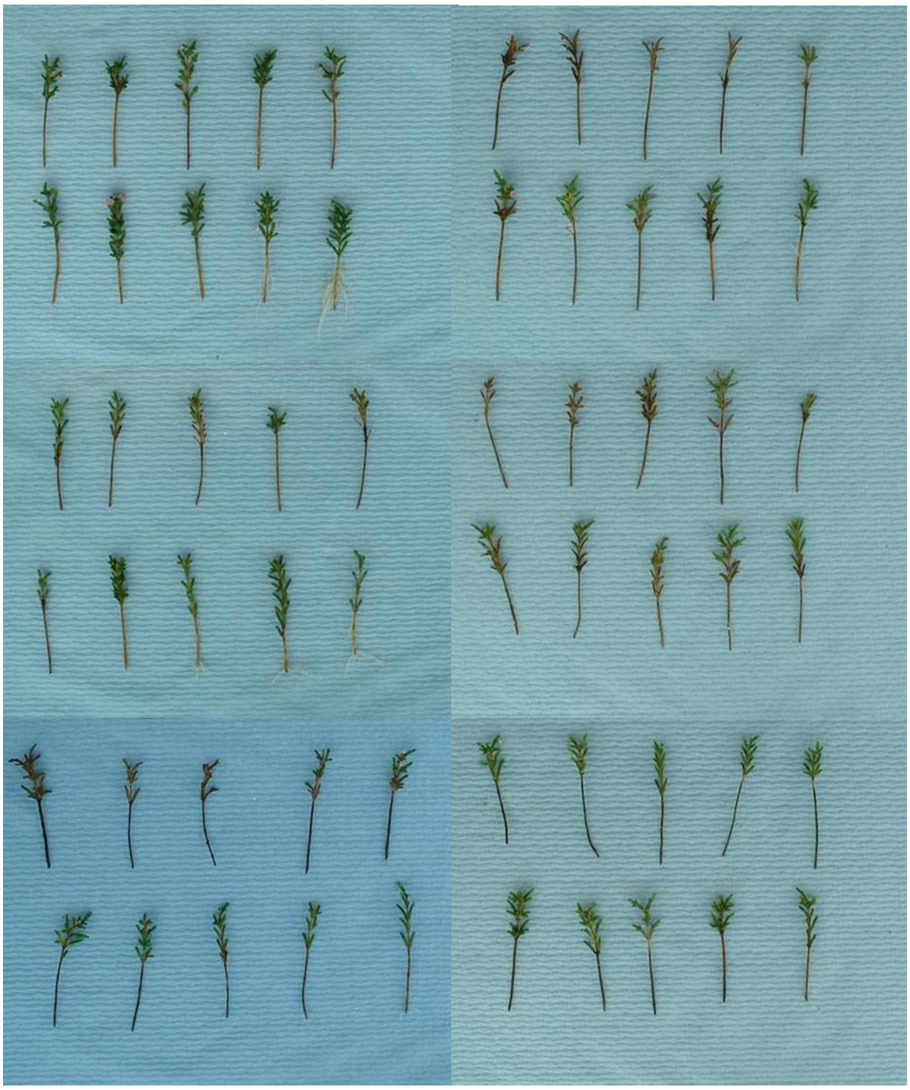
Calluna vulgaris July 2008 - grit

Rep 1 Rep 2

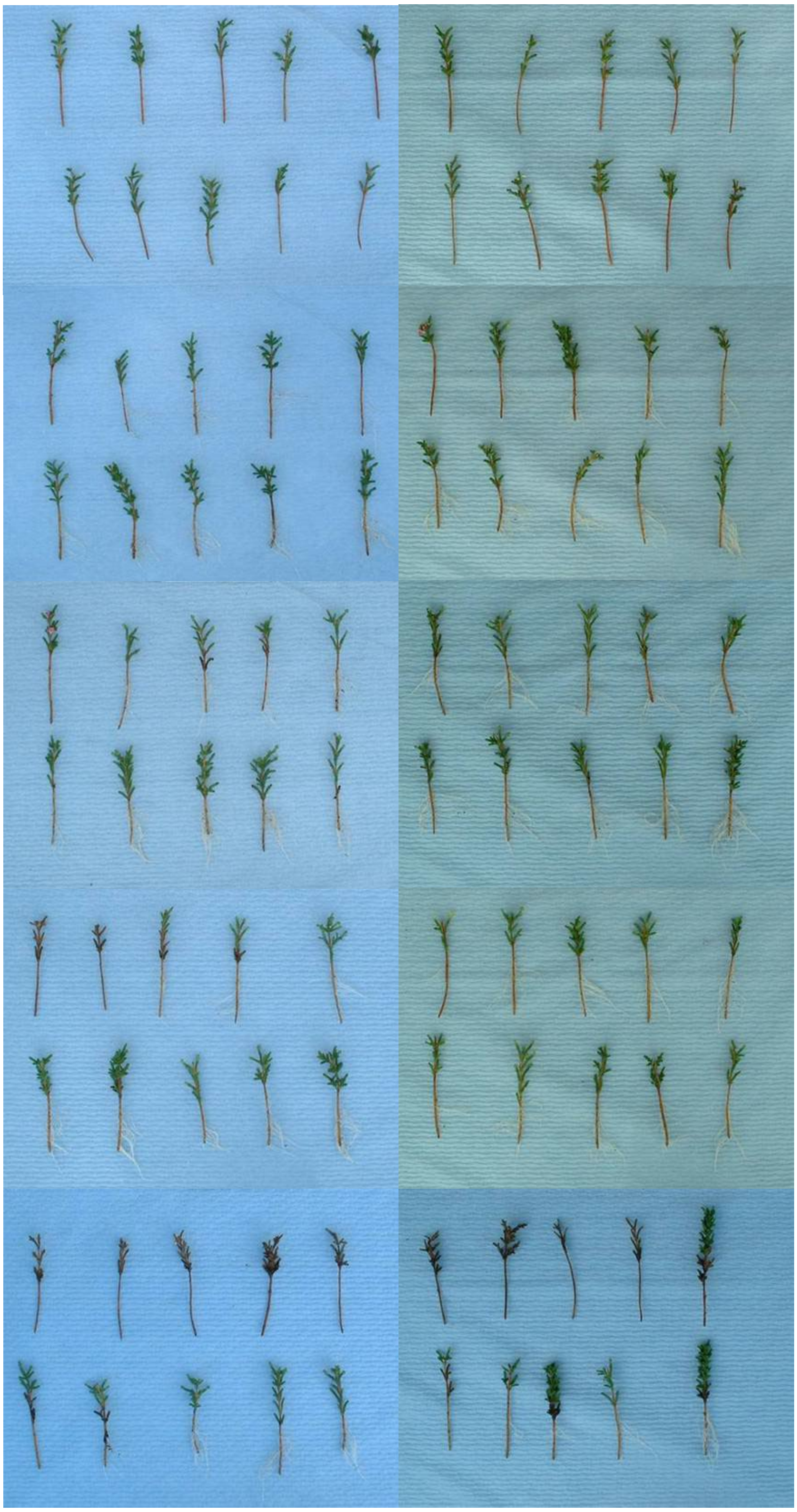
pH4
70 mg/l

pH6
70 mg/l

pH8
70 mg/l



Calluna vulgaris July 2008 - peat/perlite



Calluna vulgaris July 2008 - peat/perlite

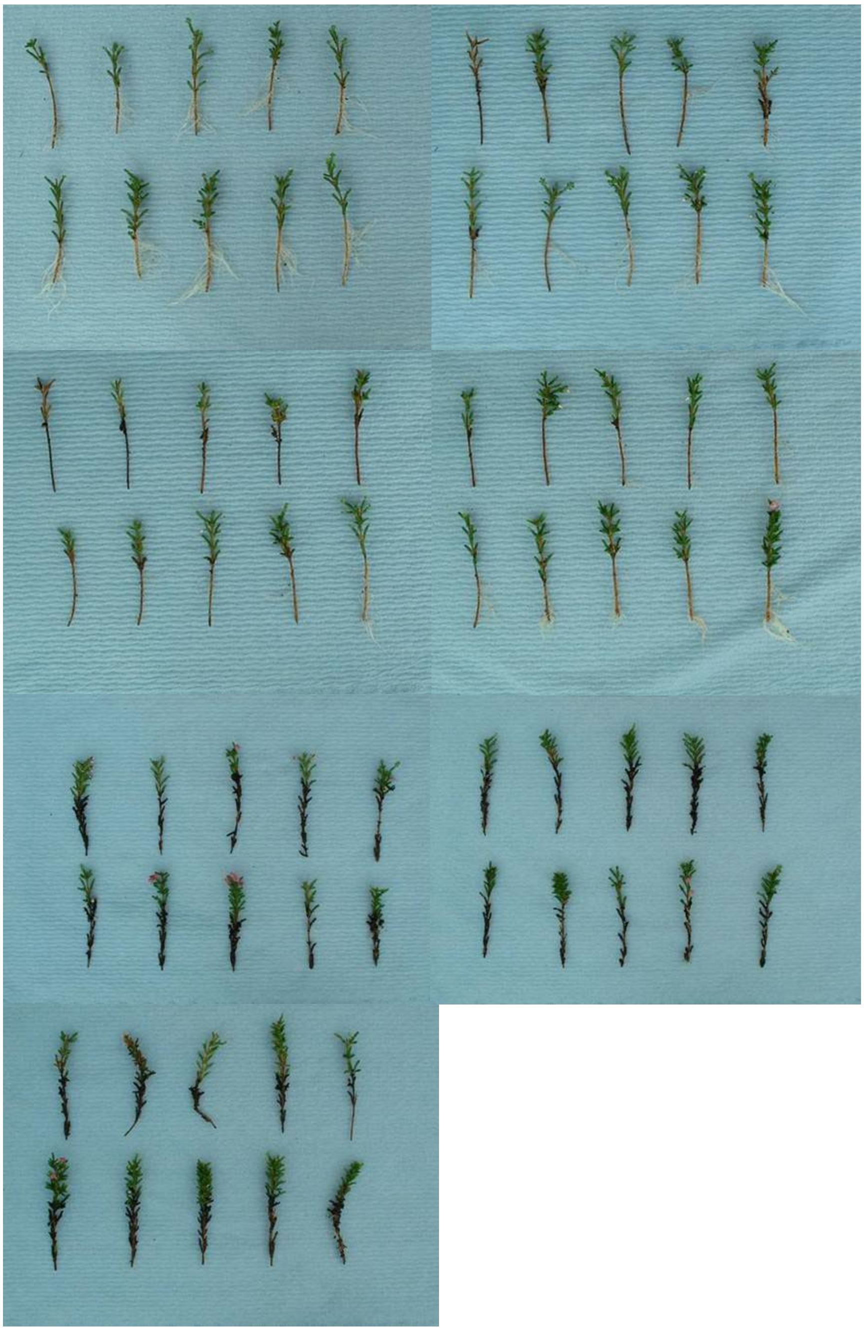
Rep 1 Rep 2

pH4
70 mg/l

pH6
70 mg/l

pH8
70 mg/l

Calluna vulgaris July 2008 - limed peat/perlite



0 lime

3.25g/l lime

10g/l lime

20g/l lime

40g/l lime

80g/l lime

120g/l lime

Cranberry July 2008 - grit

Rep 1 Rep 2

pH2
10 mg/l

pH4
10 mg/l

pH6
10 mg/l

pH8
10 mg/l

pH10
10 mg/l

Cranberry July 2008 - grit

Rep 1 Rep 2

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Cranberry July 2008 - peat/perlite

Rep 1 Rep 2

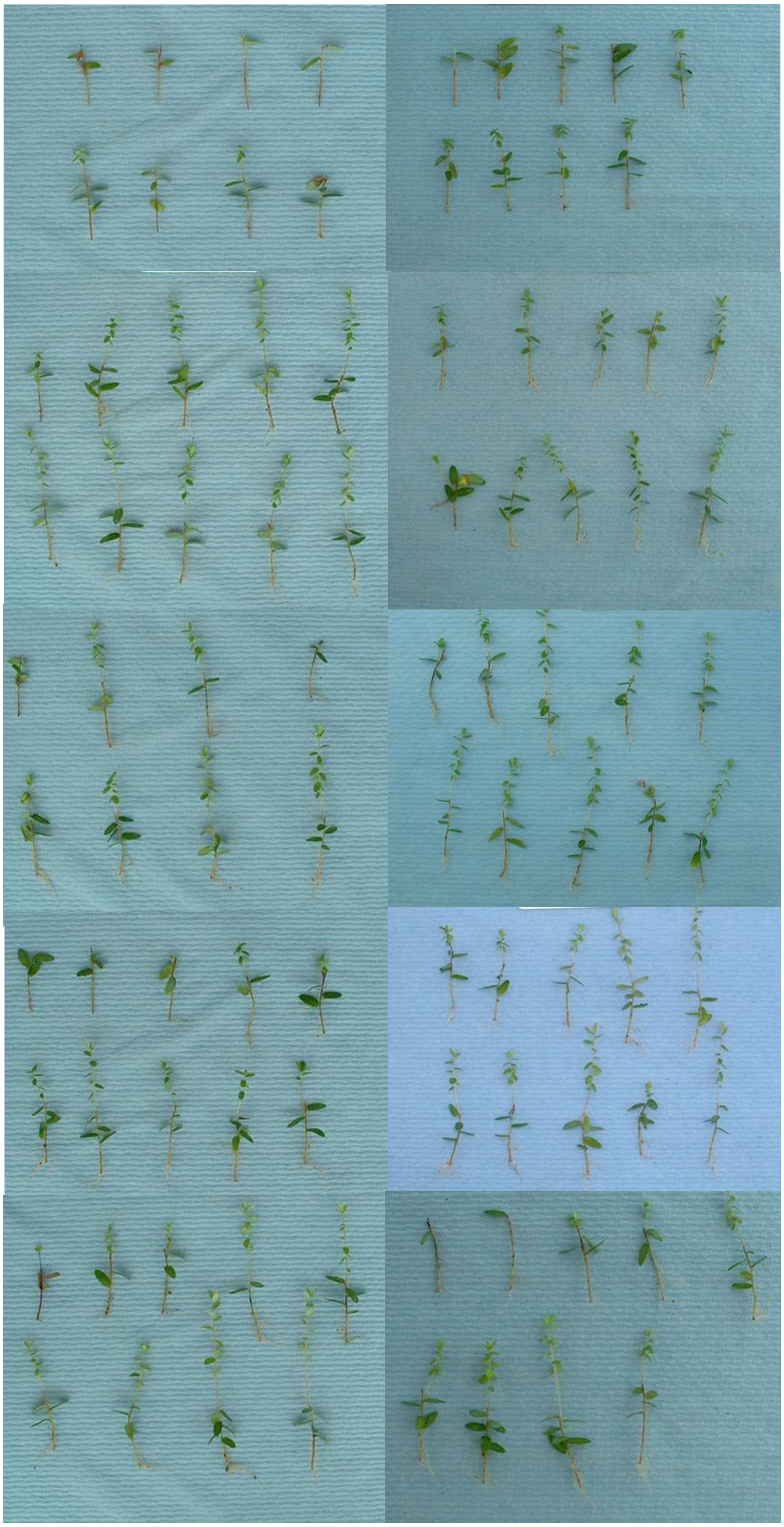
pH2
10 mg/l

pH4
10 mg/l

pH6
10 mg/l

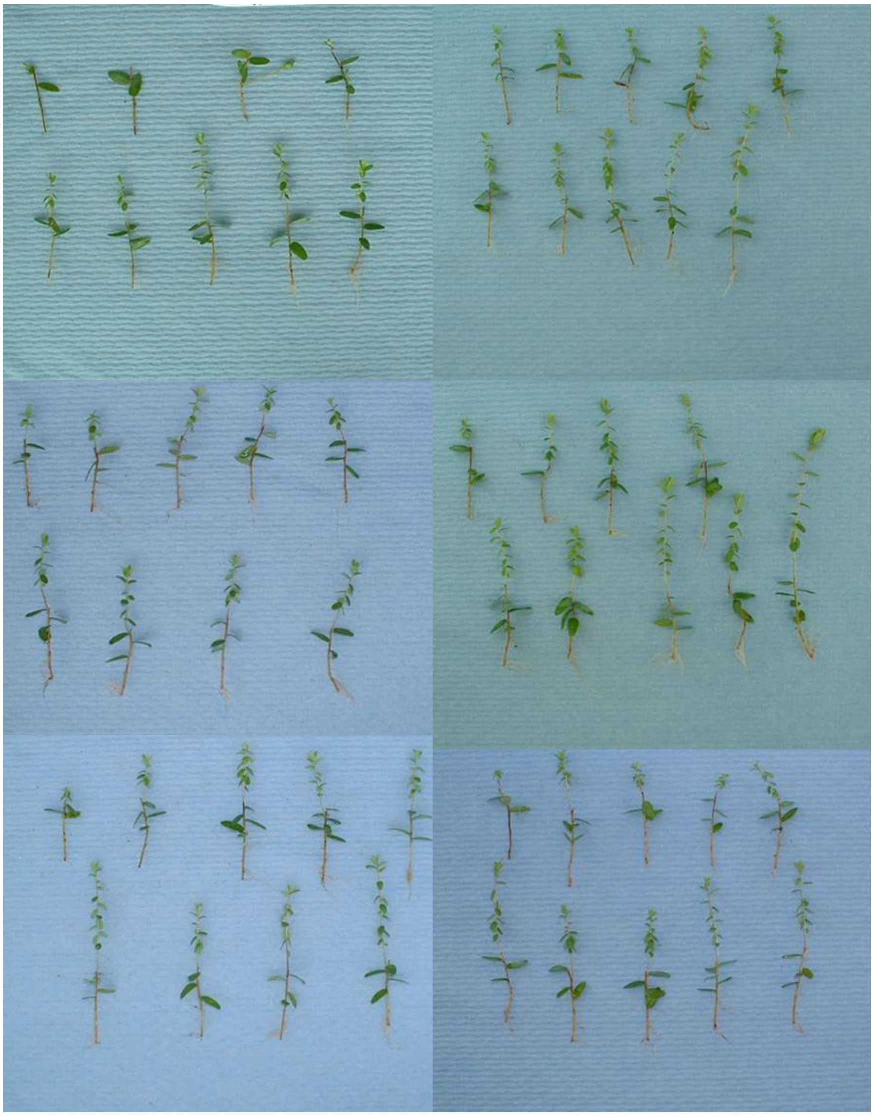
pH8
10 mg/l

pH10
10 mg/l



Cranberry July 2008 - peat/perlite

	Rep 1	Rep 2
pH4 70 mg/l		
pH6 70 mg/l		
pH8 70 mg/l		



Cranberry July 2008 - limed peat/perlite

0 lime

3.25g/l lime

10g/l lime

20g/l lime

40g/l lime

80g/l lime

120g/l lime

Erica carnea July 2008 - grit

Rep 1 Rep 2

pH2
10 mg/l

pH4
10 mg/l

pH6
10 mg/l

pH8
10 mg/l

pH10
10 mg/l

Erica carnea July 2008 - grit

Rep 1 Rep 2

pH4
70 mg/l

pH6
70 mg/l

pH8
70 mg/l

Erica carnea July 2008 - peat/perlite

Rep 1 Rep 2

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

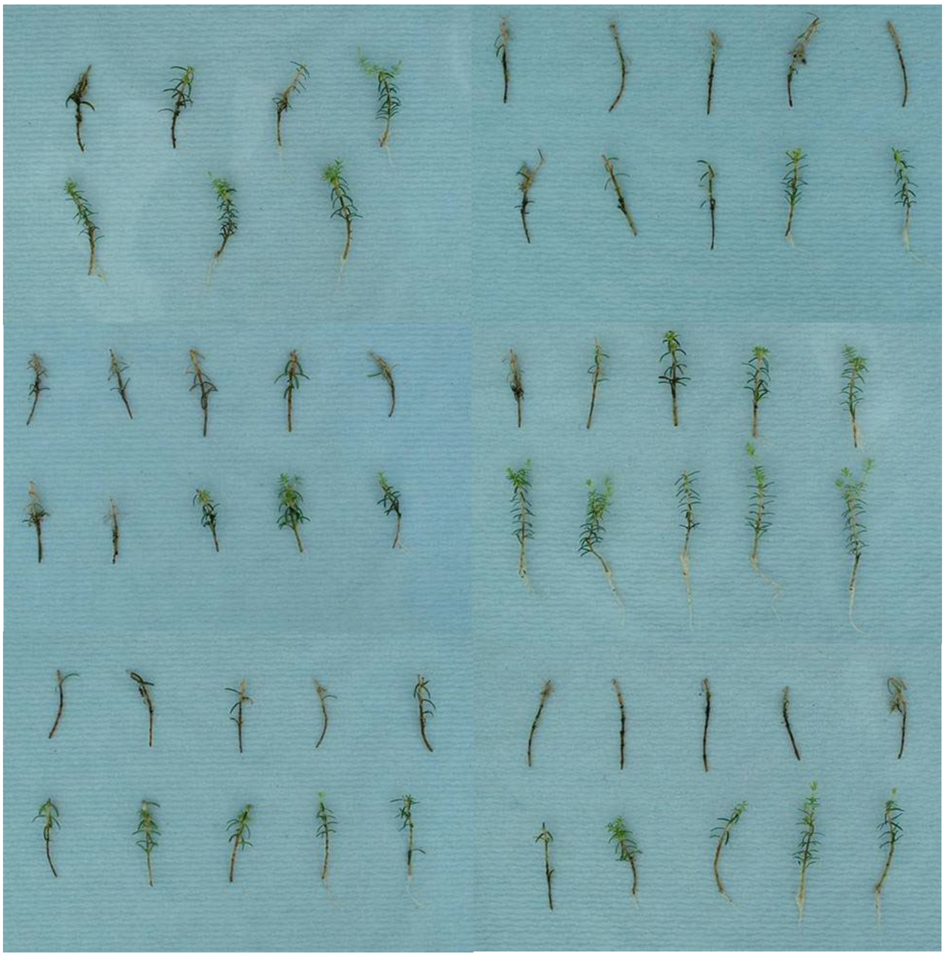
Erica carnea July 2008 - peat/perlite

Rep 1 Rep 2

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N



Erica carnea July 2008 - limed peat/perlite

0 lime

3.25g/l lime

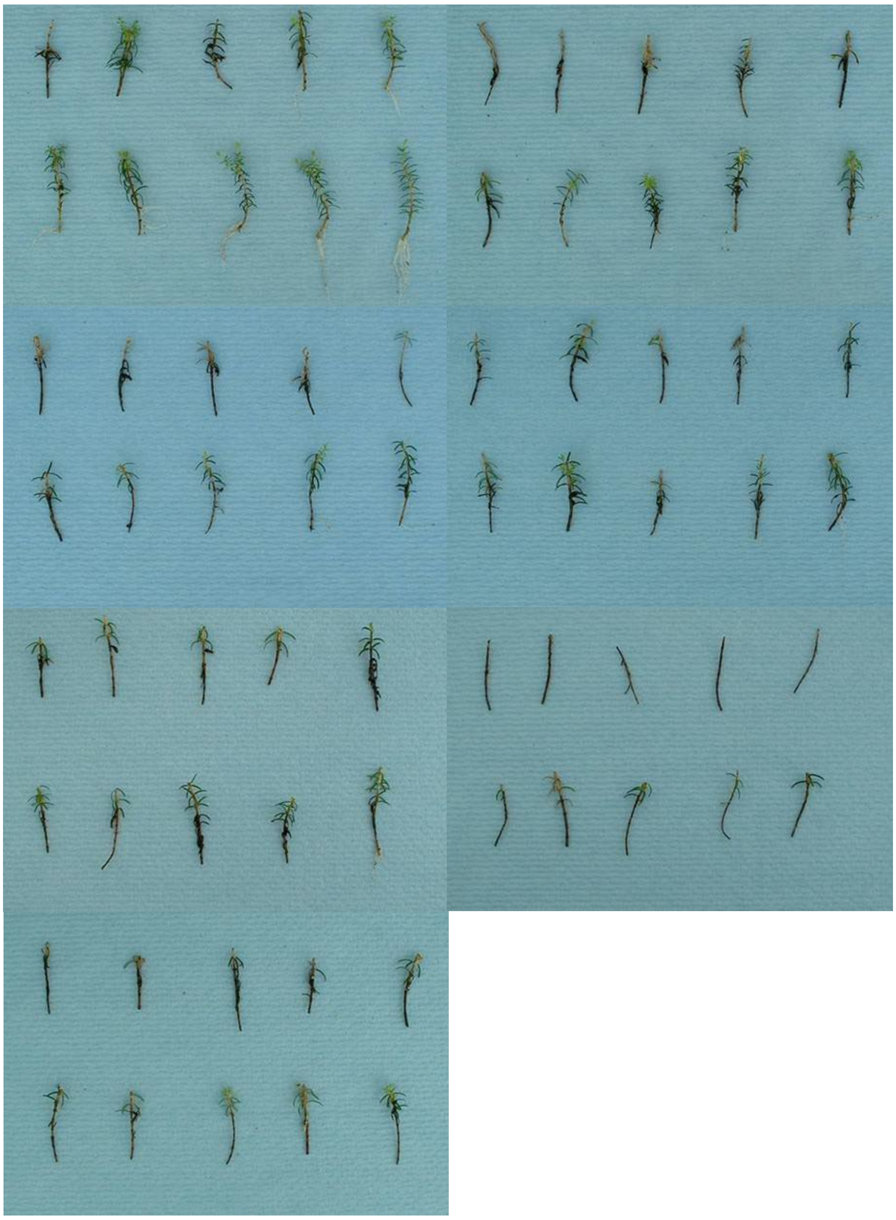
10g/l lime

20g/l lime

40g/l lime

80g/l lime

120g/l lime



Rhododendron July 2008 - grit

Rep 1 Rep 2

pH2
10 mg/l N

pH4
10 mg/l N

pH6
10 mg/l N

pH8
10 mg/l N

pH10
10 mg/l N

Rhododendron July 2008 - grit

	Rep 1	Rep 2

pH4
70 mg/l

pH6
70 mg/l

pH8
70 mg/l

Rhododendron July 2008 - peat/perlite

	Rep 1	Rep 2

pH2
10 mg/l

pH4
10 mg/l

pH6
10 mg/l

pH8
10 mg/l

pH10
10 mg/l

Rhododendron July 2008 - peat/perlite

Rep 1 | Rep 2

pH4
70 mg/l N

pH6
70 mg/l N

pH8
70 mg/l N

Rhododendron July 2008 - limed peat/perlite