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Location of project:	East Malling Research
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Key words:

Aliette 80WG, *Aquilegia*, *Bacillus*,*Chamaecyparis lawsoniana* 'Elwoodii', compost tea, copper, copper ammonium carbonate, *Cytisus*, disease, electromagnetic, Standon Etridiazole 35, fosetyl-ammonium, *Funaria hygrometrica*, Fungex, fungicide, ioniser, liverwort, *Marchantia polymorpha*, Mogeton, moss, *Phytophthora cinnamomi*, *Prunus*, *Pseudomonas*, *Pythium*, quinoclamine, *Trichoderma*.

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

AUTHENTICATION

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

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Grower summary

Headline

In the first year of this project, the "Aqua-Hort" electromagnetic copper water treatment (Figure 1) and the copper feed treatment both significantly reduced *Phytophthora cinnamomi* infection in *Chamaecyparis lawsoniana* 'Elwoodii' without any obvious adverse effect on plant growth.

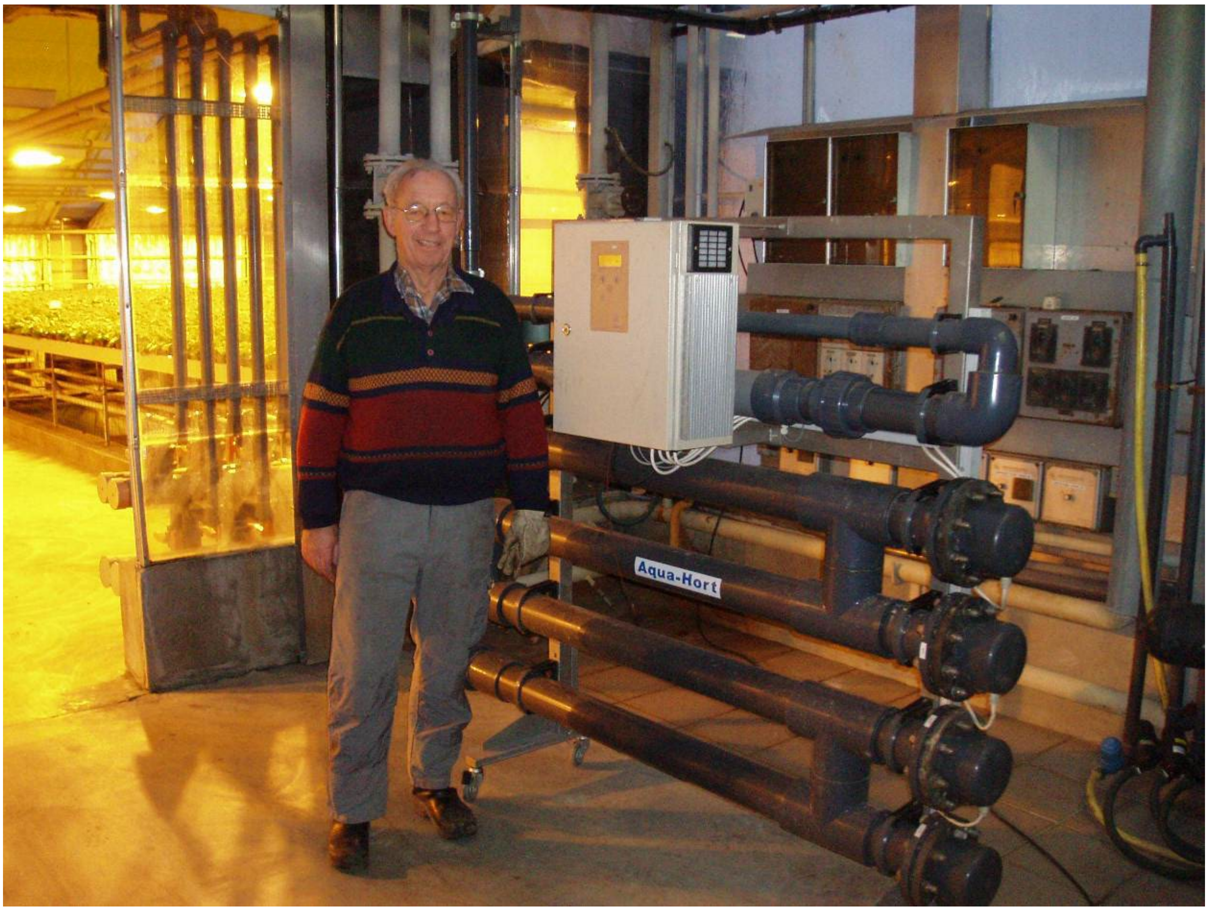

Figure 1. One of the first Aqua Hort installations on a Danish pot plant nursery, Jutland.

Background and expected deliverables

Control of root diseases caused by *Phytophthora* and *Pythium* and bacterial leaf spots such as *Pseudomonas syringae* continues to present major problems for nursery stock growers.

Water is the key means for spread of these pathogens on a nursery. Dispersal of *Phytophthora* and *Pythium* occurs by movement of zoospores in water (ncluding films of water at the base of pots), by water splash, or in recycled drainage water. Bacterial leaf spots are spread by water splash and in films of water on leaf surfaces.

It is thought that the regular addition of copper to irrigation water could substantially limit the spread of *Phytophthora*, *Pythium* and bacterial leaf spots. However, when using copper fungicide sprays to control leaf spot, treatment is often applied infrequently and there are occasions when plants are wet and insufficient copper is present to achieve pathogen control.

The use of electromagnetic water treatment with copper ions (E Cu) is claimed to enhance the activity of the copper and has been adopted by pot plant growers in Denmark for controlling a range of root infecting fungi. Initial results have been promising, but most experience has been gained with "ebb and flow" irrigation systems, and so far in the Netherlands and Denmark, there have been only two installations on nursery stock with overhead irrigation. Mini portable ionising water treatment units have recently become available, which are suitable for smaller scale growers, or treatment of specific crop batches (e.g. "Aqua-Hort Mini", Aqua-Perl Denmark ApS). Previously, such units have been large and costly to install.

As copper is known to inhibit liverwort growth, it is also intended to study the effect of the treatment on liverwort and moss control.

The expected deliverables from this work include

- An evaluation of the Aqua Hort copper ioniser system for the control of *Phytophthora* and *Pythium* root rots, bacterial leaf spot and moss and liverwort growth, compared with fungicide and biological treatments.

- To check the compatibility of the Aqua Hort copper ioniser system with biological control systems used in normal commercial practice.

- To develop guidelines for the use of the Aqua Hort copper ioniser system and its integration with biological systems on the nursery

Summary of the project and main conclusions

Phytophthora root rot study

Chamaecyparis lawsoniana 'Elwoodii' along with infector plants, were potted from plugs and grown on for 16 weeks under different water treatment regimes or with fungicide or biological control measures, designed to reduce disease spread.

Treatments

1. Untreated water at each watering
2. Aqua Hort (E Cu) water at each watering, set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar Cu concentration (3 ppm) at each watering – using 24 gm $CuSO_4$ / 1000 L
4. Fungicide treatment: Standon Etridiazole 35 incorporation at potting followed by two Aliette 80WG drenches (1 kg / 1000 L) at 6 weeks and 12 weeks after potting applying 10% of pot volume; untreated water for irrigation
5. *Trichoderma* as Bio Fungus Instant granules (2 kg / m^3) incorporated at potting; untreated water for irrigation

The results and statistical analyses are summarised in Table 1 (below). Both of the copper water treatments were very effective in controlling a high level of *Phytophthora* root rot in *Chamaecyparis lawsoniana* 'Elwoodii' reducing the incidence of plants with foliar symptoms from 8.0% (untreated) to 1.5% (E Cu treatment) or 0.8% (copper feed). There was no significant difference between the E Cu treatment and the copper feed. By contrast the standard fungicide programme of Standon Etridiazole 35 WP (etridiazole) incorporation followed by two Aliette 80 WG (fosetyl-aluminium) drenches only provided control for the first 3 months. The *Trichoderma* incorporation appeared ineffective. Plant quality was improved by both copper water treatments, but not by the chemical or biological treatments (Figure 2).

Table 1. Occurrence of *Phytophthora* symptoms on *Chamaecyparis lawsoniana* 'Elwoodii' after 16 weeks.

Treatment	**% dead plants after 16 weeks**	**Mean No. plants (of 15) with foliar symptoms**	**Root rot (%)**
1. Untreated water	43.3	8.0	85.4
2. E Cu treated water	5.0	1.5	44.2
3. Copper nutrient feed	1.7	0.8	30.4

4. Standon Etridiazole 35 incorporation, 2 x Aliette drenches	28.3	6.5	72.1
5. *Trichoderma* incorporation	31.7	7.0	80.8
F pr.	0.060	0.012	<0.001
Df	12	12	12
s.e.d	14.57	2.092	9.61

Fig 2 a) Treatment 2, Aqua Hort treatment (E Cu)

Fig 2 b) Treatment 4, Standon Etridiazole 35 followed by two Aliette drenches

Fig 2 c) Treatment 5, *Trichoderma* incorporation

Figure 2. *Phytophthora* root rot infection on *Chamaecyparis lawsoniana* 'Elwoodii'

Pythium root rot study

Aquilegia vulgaris 'Winkie Mix' along with infector plants, were potted from plugs and grown on for 16 weeks under different water treatment regimes or with fungicide or biological control measures.

Treatments

1. Untreated water at each watering
2. E Cu water at each watering, set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar Cu concentration (3 ppm) at each watering - using 24 gm $CuSO_4$ /1,000 L
4. Fungicide treatment, Standon Etridiazole 35 incorporation at potting followed by two Aliette 80WG drenches (1 kg/1,000 L) at 6 weeks and 12 weeks after potting, applying 10% of pot volume; untreated water for irrigation
5. *Bacillus spp.* (as Revive^{TM}) drench after potting (2 ml/L) applying 10% of pot volume; untreated water for irrigation

No definite conclusions could be drawn from the *Pythium* study because the *Aquilegia* plants suffered phytotoxicity from the Aliette drench (leaf purpling) and later from the copper water treatments. The wet irrigation regime (to encourage *Pythium*), the lack of drainage from the isolation trays and chemical phytotoxicity all tended to cause root deterioration regardless of treatment. For the year two experiment, lower target rates of copper will be used with a drier irrigation regime. Aliette will be replaced with an alternative chemical treatment.

Pseudomonas *leaf spot study*

Prunus laurocerasus 'Otto Luyken' along with infector plants, were grown on for 16 weeks under different water treatment regimes or with fungicide or compost tea treatments.

Treatments

1. Untreated water at each watering
2. E Cu water at each watering, set to deliver 3ppm Cu
3. Copper nutrient feed at a similar Cu concentration (3 ppm) at each watering - using 24 gm $CuSO_4$ /1,000 L
4. Fungex (copper ammonium carbonate) (50 L /1,000 L) applied to fully wet the foliage just to the point of run off, every 14 days from 13 June to 5 September; untreated water
5. Compost tea brewed (see details below) and applied at 100 ml/ L to fully wet the foliage just to the point of run off every 14 days (as above); untreated water

At the end of the experiment there were significant differences (P=0.025) between treatments in the level of leaf spot (Table 2). The biological treatment, compost tea, significantly increased the incidence of *Pseudomonas* leaf spot from 4.25 to 9.75%, an unexpected result. It is possible that some components of the compost tea brew were stimulating the growth of *Pseudomonas*. The two copper water treatments and the copper spray treatment gave no significant reduction in the incidence of *Pseudomonas syringae* leaf spot. The copper spray treatment left a heavy and unsightly deposit.

Table 2. Effect of treatment on percentage browning by leaf spot on *Prunus*.

Treatment	Leaf spot (%browning) 13/9/06
1. Untreated water	4.3
2. E Cu treated water	3.5
3. Copper nutrient feed	2.8
4. Fungex (50 mL/10L) every 14 days	2.0
5. Compost tea every 14 days	9.8
F pr.	0.025
Df	12
s.e.d	2.144

Moss and liverwort control study

Cytisus were potted from plugs along with moss and liverwort infector plants, and grown on for 16 weeks under different water treatment regimes or with fungicide or biological control measures.

Treatments

1. Plain water at each watering
2. E Cu water at each watering, set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar Cu concentration (3 ppm) at each watering - using 24 gm $CuSO_4$ / 1000 L
4. Quinoclamine (Mogeton) at 7.5 kg/ha applied in 1000 L/ha applied after potting
5. *Fusarium equiseti* culture drenched 1/6/06, 5mL per pot, repeated 26/7/06.

Neither of the copper water treatments provided significant control although there was an indication that the liverwort/moss balance was switched slightly in favour of moss. The chemical treatment Mogeton gave good control for 2 months but moss and liverwort developed subsequently. The novel biological treatment *Fusarium equiseti* was not effective – unfortunately conditions favourable to the establishment of *F. equiseti* are also very favourable to the development of liverwort.

Performance of the Aqua Hort Mini unit

The copper levels in the water treatments were monitored weekly. The Aqua Hort mini unit did not always reach the target of 3 ppm Cu and the average over the experimental period was 2 ppm. The Aqua Hort Mini does require quite a high level of conductivity in the supply water to work efficiently and it is suggested that the typical conductivity of 500 uS/cm in the East Malling water was not sufficient. For the year two experiments, a larger machine will be used. Analysis of soluble copper in the growing media showed that copper levels increased by 0.05 from 0.11 mg/L to 0.16 mg/L over the 16-week period where the water treatment was used.

Financial benefits

The Aqua Hort (Figure 1) unit proved very effective under the experimental conditions of this study for the control of *Phytophthora* root rot in *Chamaecyparis lawsoniana* 'Elwoodii'. If confirmed in other studies and in different growing systems, the potential benefits to growers who suffer persistent problems with *Phytophthora* root rots, not just on conifers but also broad-leaved shrubs and herbaceous plants, would be substantial. It is known that some nurseries have lost in excess of £75,000 of stock from *Phytophthora* infection in a year. With a purchase price of around £6,000 for a unit suitable for a medium to large nursery, and assuming the cost is written off over 10 years @ 6%, plus running costs, the annual cost to the business is approximately £1,300. There are likely to be many nurseries who lose in excess of £1,300 stock to *Phytophthora* each year.

Action points for growers

- The Aqua Hort system shows good potential for control of *Phytophthora* root rots when used with overhead irrigation and would be cost effective.

- The benefits for using the Aqua Hort unit for the control of *Pythium* root rots and the reduction in *Pseudomonas* leaf spot remain to be proven.

Science Section

Introduction

Control of root diseases caused by species of *Phytophthora* and *Pythium* continues to present problems for nursery stock growers particularly in the conifer and herbaceous perennial sectors. *Phytophthora* root rot is listed as a major problem in the conifer R & D strategy and is a ** gap (HDC gap analysis) due to the limited number of control treatments available. Bacterial leaf spots such as *Pseudomonas syringae* are also a particular problem on evergreen *Prunus*, a major landscape line. A nursery survey (HNS 71) also identified many other plants that are often affected by *Psuedomonas* including *Philadelphus* and *Spiraea*; both are important lines. Follow-up work (HNS 91) did not identify a satisfactory control measure and control of bacterial leaf spots in nursery stock is a *** gap. Individual nurseries have lost production in excess of £75,000 due to these diseases. The industry loss is estimated to be in excess of £1.5m per annum.

Water is the key means for spread of these diseases on a nursery. Dispersal of *Phytophthora* and *Pythium* occurs by movement of zoospores in water, including films of water at the base of pots, water splash, or in recycled drainage water. Bacterial leaf spots are spread by water splash and in films of water on leaf surfaces.

The regular addition of copper to irrigation water could substantially limit spread of *Phytophthora*, *Pythium* and bacterial leaf spots. With copper fungicide sprays, treatment is often applied infrequently and occasions are likely to occur when plants are wet and insufficient copper is present to achieve pathogen control. The use of electromagnetic water treatment with copper ions is claimed to enhance the activity of the copper (Goldsworthy *et al.,* 1999) and has been adopted by pot plant growers in Denmark for control of a range of root infecting fungi (Pederson, 2003). The main experience so far has been with “ebb and flow” irrigation systems. There have been only two installations, in Holland and Denmark, on nursery stock with overhead irrigation. Recently, mini portable ionising water treatment units have become available, suitable for smaller scale growers, or treatment of specific crop batches (e.g. “Aqua-Hort Mini”, Aqua-Perl Denmark ApS). Previously, units have been large and costly to install.

The commercial objective of this work is to develop a simple water treatment system compatible with current practice that results in improved control of *Pythium* and *Phytophthora* root rots, bacterial leaf spots and liverworts and moss.

The scientific objectives were:

1. To determine the effectiveness of routinely irrigating plants with copper-ionised water in preventing the development of *Phytophthora* root rot, *Pythium* root rot, bacterial leaf spot and moss and liverwort growth.

2. To compare the effectiveness of copper treatment of water with a standard chemical and biological control treatment for each disease or weed infestation.

The technical objectives were:

1. To test the efficacy of electromagnetic copper (E Cu) water treatment in controlling the spread of *Phytophthora* root rot in *Chamaecyparis* 'Elwoodii', compared with a standard fungicide treatment, a copper nutrient feed in the irrigation water, and a biological control (*Trichoderma)* sold for the control of fungal disease including *Phytophthora* (Vitagrow Fertilisers Ltd)
2. To test the efficacy of E Cu water treatment in controlling the spread of *Pythium* root rot in *Aquilegia vulgaris*, compared with a standard fungicide treatment, a copper nutrient feed in the irrigation water, and a biological control (*Bacillus* spp. as Revive^{TM}) supplied by Agralan Ltd as a root promoter.
3. To test the efficacy of E Cu water treatment in controlling the spread of *Pseudomonas* leaf spot in *Prunus,* compared with a copper fungicide programme, a copper nutrient feed, and routine applications of compost tea.
4. To test the efficacy of E Cu water treatment in limiting the establishment of moss and liverwort on infested *Cytisus* plugs when potted up as liners, compared with a copper nutrient feed, a chemical treatment and a novel biological control, *Fusarium equiseti.*

Materials and methods

In the first year of this project efficacy experiments were done at East Malling Research on four nursery stock subjects grown on benching in a polytunnel with specific diseases or weed infestation as outlined in the previous section.

Treatments for all four subjects followed a similar pattern:

1. Irrigation with untreated water
2. Irrigation with E Cu treated water using an Aqua-Hort Mini copper ioniser set at 3 ppm Cu
3. Irrigation with an enhanced level copper nutrient feed calculated to apply 3 ppm Cu
4. Industry standard chemical control, irrigated with untreated water
5. Industry standard biological control, irrigated with untreated water

The experiment was laid out as a randomised complete block split-plot experiment with 4-fold replication. Within the experiment, four studies were run, each study with the five basic treatments above, with differences in the chemical and biological controls used according to the diseases. Further details of the chemical treatments can be found in Appendix 1. Results were examined by analysis of variance (ANOVA) or by a non-parametric test (e.g. Friedman's test) where conditions for ANOVA did not hold true.

The four studies run in year 1 were:

1. *Phytophthora* root rot control.
2. *Pythium* root rot control.
3. *Pseudomonas* leaf spot control.
4. Moss and liverwort control.

Each plot consisted of 15 plants of *Chamaecyparis* 'Elwoodii' (12 for *Prunus* used in study 3) from each of the four studies, creating four sub-plots within a plot.

1. Phytophthora *root rot study*

Three hundred *Chamaecyparis* 'Elwoodii' plants were potted from plugs into 9 cm pots (25/4/06) using a growing medium comprising: sphagum peat: sterilised loam 90:10 by volume + Osmocote Plus 12-14 month (4 kg/m^3), starter feed (14% N, 16% P_2O_5, 18% K_2O) at 0.5 kg/m^3, + wetter, + Intercept (imidacloprid) (280 gm/m^3). For the plants in treatment 4, Standon Etridiazole 35 (40 gm/m^3) was added to the media at potting – diluting the fungicide 1:10 with fine sand to facilitate even mixing. For plants in treatment 5, *Trichoderma* as Bio-Fungus Instant granules (2 kg / m^3) was added to the media at potting. Bio-Fungus is reported to control *Phytophthora* root rots (Vitagrow Fertilisers Ltd). For each sub-plot, 15 healthy plants were grouped around two infector plants and placed in an isolation tray (90 cm x 30 cm with no holes). One tray of plants per plot was then placed in the trial area on benching in the polytunnel. The infector plants had been prepared by inoculating them with *Phytophthora cinnamomi;* plants showing initial symptoms of *Phytophthora* root rot were chosen for use as infector plants. Treatment details are given in Table 3.

Table 3. Treatment list for experiment on *Pythophthora* root rot control

1. Untreated water at each watering
2. E Cu water at each watering, set at 3 ppm Cu
3. Copper nutrient feed at a similar (3 ppm) Cu concentration at each watering – using 24 gm $CuSO_4$ /1,000 L
4. Fungicide treatment, Standon Etridiazole 35 incorporation at potting followed by two Aliette 80 WG drenches (1 kg /1,000 L) at 6 weeks (27/6/06) and 12 weeks (8/8/06) after potting applying 10% of pot volume; untreated water for irrigation
5. *Trichoderma* as Bio Fungus Instant granules 2 kg / m^3 incorporated at potting; untreated water for irrigation.

Irrigation treatments were maintained for 16 weeks from 16/5/06.

Assessments

Plants were visually assessed for foliar symptoms (foliage or stem browning, stunting or wilt) of *Phytophthora* root rot infection on 07/06/06, 20/6/06, 20/7/06 and 13/9/06. At the final assessment the number of dead plants was recorded and the severity of root rotting was assessed by breaking the root ball into approximate quarters longitudinally. Plant quality was recorded using a scoring system (0 to 5 scale) using the following key:

0 all plants dead or dying.

1 most plants unthrifty, none are marketable.

2 most plants unmarketable; 1 or 2 plants per plot are marketable (good growth, no leaf spots or discolouration).

3 most plants are marketable, but poor quality (discoloured growth or leaf spots present).

4 most plants marketable and good quality.

5 all plants marketable, most of excellent quality with no defects.

After the experiment was completed plant samples were taken for further analysis. A few discoloured or rotting roots were collected from 5 plants per plot. The roots were washed to remove compost and surface sterilised by ethanol dip. Ten pieces of roots per plot were plated out onto a *Phytophthora* – selective agar medium (P5ARP) and checked for *Phytophthora* after 7 days. The number of roots per plot that developed *Phytophthora* were then recorded.

2. Pythium *root rot study*

Three hundred *Aquilegia vulgaris* 'Winkie Mix' plants were potted from plugs into 9 cm pots (25/4/06) using the growing medium as above. For the plants in treatment 4, Standon Etridiazole 35 (40 gm/m^3) was added to the media at potting – diluting the fungicide 1:10 with fine sand to facilitate even mixing. The plants in treatment 5 were drenched with *Bacillus* as Revive Liquid (2 ml/L) applying 10% of pot volume on 15/5/06. For each sub-plot group, 15 healthy plants were grouped around 2 infector plants (plants with *Pythium* root rot) and placed in an isolation tray. One tray of plants per plot was then placed in the trial area on benching in the polytunnel. Treatments are given in Table 4.

Table 4. Treatment list for experiment on *Pythium* root rot control.

1. Untreated water at each watering
2. E Cu water at each watering, set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar (3 ppm) Cu concentration at each watering - using 24 gm $CuSO_4$ / 1000 L
4. Fungicide treatment, Standon Etridiazole 35 incorporation at potting followed by two Aliette 80WG drenches 1 kg / 1000 L at 6 weeks (27/6/06) and 12 weeks (8/8/06) after potting, applying 10% of pot volume; untreated water for irrigation
5. *Bacillus spp.* (as Revive^{TM}) drench after potting 2 mL / L applying 10% of pot volume; untreated water for irrigation

Irrigation treatments were maintained for 16 weeks from 16/5/06.

Aquilegia plants were sprayed for powdery mildew control using Systhane 20EW at 0.45 mL/L applied to run off on 5/9/06.

Assessments

Plants were visually assessed for foliar symptoms (foliage or stem browning, stunting or wilt) of *Pythium* root rot infection on 07/06/06, 20/6/06, 20/7/06 and 13/9/06. At the final assessment the number of dead plants was recorded and the severity of root rotting was assessed by breaking the root ball into approximate quarters longitudinally. Plant quality was recorded using a scoring system (0 to 5 scale) as for the *Phytophthora* study.

After the experiment was completed, plant samples were taken for further analysis. A few discoloured or rotting roots were collected from 5 plants per plot. The roots were washed to remove compost and surface sterilised by ethanol dip. Ten pieces of roots per plot were plated out onto PDA + streptomycin and checked for *Pythium* after 3 days. The number of roots per plot that developed *Pythium* were then recorded.

3. Pseudomonas *leaf spot study*

Two hundred and forty 3 Litre *Prunus laurocerasus* 'Otto Luyken' plants were obtained already potted. For each sub-plot, 12 plants were grouped around a plant infected with *Pseudomonas syringae* leaf spot and placed in an isolation tray. One tray of plants was then placed in the trial area on benching in the polytunnel. Treatments are given in Table 5.

Table 5. Treatment list for experiment on *Pseudomonas* leaf spot control.

1. Untreated water at each watering
2. E Cu water at each watering , set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar (3 ppm) Cu concentration at each watering - using 24 gm $CuSO_4$ / 1000 L
4. Fungex applied at 50 L / 1000 L applied to fully wet the foliage just to the point of run off, every 14 days (13/6, 27/6, 11/7, 25/7, 8/8, 23/8, 5/9/06), untreated water
5. Compost tea brewed (see details below) and applied at 100 mL / L to fully wet the foliage just to the point of run off every 14 days (dates as above); untreated irrigation water

Compost tea was prepared using a Microfarming Xtractor 100 Litre brewer using the Microfarming fungal dominant compost package. Mains water was warmed to glasshouse temperature, 15-20°C. The brewer was run for 1 hr to remove chlorine and bring oxygen levels up to 6 ppm. A quarter of the additive package was mixed in warm water then added to 50 litres water in the brewer with 5 ml sunflower oil to prevent foaming. The brewer was run for 18 hours with the lid off. After brewing the solution was allowed to settle for 10 minutes then filtered before use, diluted as above.

Irrigation treatments were maintained for 16 weeks from 16/5/06.

Assessments

Plants were visually assessed for percentage leaf area affected by brown leaf spotting, the foliar symptoms of *Pseudomonas* infection, on 07/06/06, 20/6/06, 20/7/06 and 13/9/06.

4. *Moss and liverwort control study*

Three hundred *Cytisus* were potted from plugs into 9 cm pots using growing media as above. For the plants in treatment 4, quinoclamine was applied as a spray (using Mogeton 7.5 kg/ha applied in 1000 L/ha) on 15/5/06. For each sub-plot, 15 plants were grouped around an infector plant (with liverwort) in an isolation tray. One tray of plants was then placed in the trial area on benching in the polytunnel. The biocontrol treatemnt was *Fusarium equiseti;* this fungus is reported to give control of liverwort (HNS126). Treatment details are given in Table 6.

Table 6. Treatment list for experiment on moss and liverwort control.

1. Plain water at each watering
2. E Cu water at each watering, set to deliver 3 ppm Cu
3. Copper nutrient feed at a similar (3 ppm) Cu concentration at each watering - using 24 gm $CuSO_4$ / 1000 L
4. Quinoclamine (Mogeton) 7.5 kg/ha applied in 1000 L/ha applied after potting
5. *Fusarium equiseti* culture drenched 1/6/06, 5 mL per pot applied as a mixture of spores and mycelium suspended in a sterile water with 0.05% Tween 20 and 0.01% glucose. Application repeated 26/7/06.

Irrigation treatments were maintained for 16 weeks from 16/5/06.

Cytisus plants received a liquid feed of Sangral 1:1:1 on 25/7/06, 3/8/06 and 23/8/06.

Assessments

Plants were assessed for the percentage cover of liverwort and moss over the growing media on 07/06/06, 20/6/06, 20/7/06 and 13/9/06.

Nutrient level monitoring

A 500 ml growing media sample was taken at the start of the experiment (18/5/06) and at the end of the experiment (14/9/06) from a representative selection of plants and analysed for water soluble macro and micro nutrients determined by extraction of 1/15th density in 400ml deionised water to BS 4156 1990. Mains water, copper feed and E Cu water samples were taken weekly and analysed for dissolved copper (mg/L).

Results & discussion

1. Phytophthora *root rot study*

At 3 and 5 weeks after treatments commenced, there were no significant differences between treatments in foliar symptoms of *Phytophthora* root rot (Table 7). Two months from potting, disease levels were still at a relatively low level with no significant difference between the water treatments. At this stage however, the fungicide treatment gave a significantly better control of foliar symptoms (0.3 plants affected) compared with the biological treatment *Trichoderma* (3 plants affected). At the final assessment 4 months after potting, the number of plants with foliar symptoms and the number of dead plants in the two copper treatments was still very low. However, both the fungicide treatment and the biological treatment were less effective giving only numerical (non-significant) reductions in foliar symptoms and the number of dead plants (Table 7 and 8). The two copper treatments reduced the proportion of roots from which *Phytophthora* was recovered at P=0.07 (Table 9). The *Trichoderma* treatment also gave a numerical (non-significant) reduction in the level of *Phytophthora* isolated from the root tissue. Plant quality was improved by both copper water treatments but not by the chemical or biological treatments (Table 8).

The amount of dead root was reduced by the two copper treatments from around 85% in the control to 30-44%. There was no significant difference between the E Cu treatment and the copper feed (Table 9).

Table 7. Effect of increased copper in irrigation water, a fungicide treatment and a biological control treatment on foliar symptoms of *Phytophthora* root rot on Chamaecyparis

Treatment	**Mean No. of plants per plot with leaf or stem browning, stunting or wilt[A]**			
	7 June	**20 June**	**7 July**	**13 Sept**
1. Untreated water	0.3	2.5	0.8	8.0
2. E Cu treated water	0.0	3.8	1.0	1.5
3. Copper nutrient feed	0.0	1.5	0.8	0.8
4. Standon Etridiazole 35 incorp, Aliette x2 drench	0.0	0.5	0.3	6.5
5. *Trichoderma* incorporated	0.0	3.8	3.0	7.0
F pr.	NS	NS	0.006	0.012
df	12	12	12	12
s.e.d	0.1581	1.639	0.609	2.092

A = 15 plants per treatment

Table 8. Effect of increased copper in irrigation water, a fungicide treatment and a biological control treatment on plant quality and occurrence of dead plants of *Chamaecyparis*

Treatment	**Final Assessment – 13/9/06**	
	% dead plants	**Plant Quality (0-5) (Friedman's Test Estimated Medians)**
1. Untreated water	43.3	2.7
2. E Cu treated water	5.0	3.7
3. Copper nutrient feed	1.7	4.8
4. Standon Etridiazole 35 incorp, Aliette x2 drench	28.3	2.3
5. *Trichoderma* incorp.	31.7	2.5
F pr.	0.060	0.036 (0.021*)
Df	12	4
s.e.d	14.57	S=10.35 (11.66*)

*adjusted for ties

Table 9. Effect of increased copper in irrigation water, a fungicide treatment and a biological control treatment on root rot and recovery of *Phytophthora* from roots – September 2006 of *Chamaecyparis*

Treatment	**Mean no. root pieces from which *Phytophthora* was recovered**[A]	**Root rot (%)**
1. Untreated water	4.00	85.4
2. E Cu treated water	0.00	44.2
3. Copper nutrient feed	1.25	30.4
4. Standon Etridiazole 35 incorp, Aliette x2 drench	4.25	72.1
5. *Trichoderma* incorporated	2.00	80.8
F pr.	0.071	<0.001
Df	12	12
s.e.d	1.518	9.61

A 10 plants per treatment

2. Pythium *root rot study*

None of the treatments gave effective control of *Pythium* (Tables 10, 11 & 12). Results were complicated by phytotoxicity to *Aquilegia* (leaf browning and stunting) from both copper treatments. The adverse effect of the copper treatment was cumulative, particularly in the case of the copper nutrient feed and resulted in poorer plant quality scores. There were no significant effects from any of the treatments on the percentage of root disease or the proportion of roots from which *Pythium* was isolated.

Table 10 Effect of increased copper in the irrigation water, a fungicide treatment and a biological control treatment on foliar symptoms of *Pythium* root rot on *Aquilegia*

Treatment	**Mean No. of plants per plot (of 15) with leaf or stem browning, stunting or wilt.**			
	7 June	**20 June**	**7 July**	**13 Sept**
1. Untreated water	3.5	1.5	0.3	5.5
2. E Cu treated water	2.5	2.3	6.3	6.5
3. Copper nutrient feed	2.0	0.0	6.0	10.0
4. Standon Etridiazole 35 incorp, Aliette x2 drench	1.8	0.8	0.0	5.0
5. *Bacillus* incorp.	2.3	0.5	1.0	5.3
F pr.	NS	0.036	0.018	NS
Df	12	12	12	12
s.e.d	1.289	0.655	2.091	2.154

Table 11. Effect of increased copper in the irrigation water, a fungicide treatment and a biological control treatment on *Aquilegia* quality – 13 September 2006.

Treatment	**% dead plants**	**Plant Quality (0-5) (Friedman's Test Estimated Medians)**
1. Untreated water	5.0	2.60
2. E Cu treated water	6.7	1.30
3. Copper nutrient feed	15.0	0.40
4. Standon Etridiazole 35 incorp, Aliette x2 drench	5.0	2.00
5. *Bacillus* incorp.	1.7	1.70
F pr.	NS	0.148 (0.115*)
Df	12	4

s.e.d	6.69	S=6.80 (7.45*)

*adjusted for ties

Table 12. Effect of increased copper in the irrigation water, a fungicide treatment and a biological control treatment on root rot and recovery of Pythium from roots of *Aquilegia.*

Treatment	**Final Assessment – 13 Sept**	
	Man no. roots (of 10) from which *Pythium* was recovered	**Root rot (%)**
1. Untreated water	2.3	73.8
2. E Cu treated water	9.3	93.3
3. Copper nutrient feed	4.8	78.8
4. Standon Etridiazole 35 incorp, Aliette x2 drench	3.8	73.3
5. *Trichoderma* incorp.	7.5	80.8
F pr.	NS	NS
Df	12	12
s.e.d	2.719	10.37

3. Pseudomonas *leaf spot study*

Levels of *Pseudomonas* leaf spot were relatively low in spite of the presence of an infector plant in each plot and overhead watering (Table 13). The two copper water treatments and the copper spray treatment numerically reduced the incidence of leaf spot and slightly improve plant quality although these effects were not statistically significant (Table 14). The copper spray treatment left a heavy and unsightly deposit. The biological treatment, compost tea, significantly increased the incidence of *Pseudomonas* leaf spot from 4.3 to 9.8% (Table 13).

Table 13. Effect of increased copper in the irrigation water, a fungicide treatment and compost tea on bacterial leaf spot of *Prunus*.

Treatment	Leaf spot (% of leaf area with brown spots)			
	7 June	20 June	7 July	13 Sept
1. Untreated water	0	3.3	1.8	4.3
2. E Cu treated water	0	2.8	1.5	3.5
3. Copper nutrient feed	0	2.8	2.3	2.8
4. Fungex (50 mL/10L) every 14 days	0	2.3	1.5	2.0
5. Compost tea every 14 days	0	2.5	2.3	9.8
F pr.		NS	NS	0.025
Df		12	12	12
s.e.d		0.713	0.566	2.144

Table 14. Effect of increased copper in the irrigation water, a fungicide treatment and compost tea on plant quality of *Prunus*

Treatment	Final Assessment – 13 Sept
	Plant Quality (0-5) (Friedman's Test Estimated Medians)
1. Untreated water	2.8
2. E Cu treated water	3.0
3. Copper nutrient feed	3.1
4. Fungex (50 mL/10L) every 14 days	3.0
5. Compost tea every 14 days	2.1
F pr.	0.471 (0.235*)
Df	4
S	3.55 (5.57*)

*adjusted for ties

4. *Moss and liverwort control study*

The chemical treatment Mogeton was the most effective in controlling moss and liverwort, with almost complete control for two months. However, after four months levels had increased to cover 36% of the pot surface. This was still a significant reduction compared to the control with 70%. None of the other treatments were effective at controlling both moss and liverwort. The copper water treatments appeared to slightly reduce the incidence of liverwort, however moss increased instead.

Growing media and water analyses

Analysis of the growing media (see Appendix 2) at the start and the conclusion of the experiment showed that water soluble copper levels increased from 0.11 mg/L to 0.14 mg/L for growing media with the E Cu treatment and to 0.16 mg/L for growing media with the copper feed treatment. Where plain water was given, the level remained virtually the same.

Water from all three irrigation treatments was monitored weekly for copper levels (see Appendix 2). It was soon apparent that the copper output from the ioniser was somewhat variable, being generally lower than the target 3 ppm, averaging 2 ppm over the 3 months of the experiment. The copper feed was similarly variable but the average rate was comparable with the E Cu.

Table 15. Effect of increased copper in the irrigation water, a herbicide and a biological control treatment on the occurrence of liverwort and moss (% pot cover) on Cytisus.

Treatment	**7 June**		**20 June**		**20 July**		**13 Sept**
	% Liverwort	**% Moss**	**% Liverwort**	**% Moss**	**% Liverwort**	**% Moss**	**% Liverwort & Moss**
1. Untreated water	0	0	0.0	2.0	0.5	13.8	70.5
2. E Cu treated water	0	0	0.0	4.0	0.3	18.2	84.0
3. Copper nutrient feed	0	0	0.0	7.5	0.0	23.0	78.8
4. Mogeton 7.5 kg/ha	0	0	0.0	0.0	0.3	0.0	36.5
5. *Fusarium equiseti* drench x2	0	0	1.0	2.8	1.8	5.5	69.2
F pr.			NS	NS	NS	0.002	0.084
Df			12	12	12	12	12
s.e.d.			0.632	2.553	1.039	4.61	16.02

Conclusions

The copper water treatments were both very effective in controlling a high level of *Phytophthora* root rot in *Chamaecyparis lawsoniana* 'Elwoodii', reducing the percentage of dead plants at the end of the experiment from 43% (untreated) to 5% (E Cu treatment) or 1.7% (copper feed) (P = 0.06).

There was no significant difference between the E Cu treatment and the copper feed. By contrast the standard fungicide programme of Standon Etridiazole 35 incorporation followed by two Aliette 80 WG drenches provided control of foliar symptoms for the first 3 months, but at 4 months the number of dead plants was 28%. Possibly more effective control would have been obtained with different fungicide treatments (e.g. drenches of Standon Etridiazole 35 WP rather than Aliette 80 WG). The *Trichoderma* incorporation appeared ineffective.

No definite conclusions could be drawn from the *Pythium* study because the *Aquilegia* plants suffered phytotoxicity from the copper water treatments. The wet irrigation regime (to encourage *Pythium*), the lack of drainage from the isolation trays and chemical phytotoxicity all tended to cause root deterioration regardless of treatment. For the year two experiment, lower target rates of copper will be used with a drier irrigation regime. Aliette will be replaced with an alternative chemical treatment.

The two copper water treatments and the copper spray treatment all appeared to reduce the incidence of *Pseudomonas syringae* leaf spot and to slightly improve plant quality although these effects were not statistically significant. Levels of leaf spot in the experiment were relatively low - the treatments need to be tested further under greater disease pressure.

The copper spray treatment left a heavy and unsightly deposit. The biological treatment, compost tea, significantly increased the incidence of *Pseudomonas* leaf spot from 4.3% to 9.8%, an unexpected result. It is possible that some components of the compost tea brew were stimulating the growth of *Pseudomonas*.

The moss and liverwort study was less encouraging. Neither of the copper water treatments provided overall control although there was an indication that the liverwort/moss balance was switched slightly in favour of moss. The chemical treatment Mogeton gave good control for 3 months but moss and liverwort developed subsequently. The novel biological treatment *Fusarium equiseti* was not effective – unfortunately conditions favourable to the establishment of *F. equiseti* are also very favourable to the development of liverwort.

There were problems achieving the target level of 3 ppm Cu from the Aqua Hort Mini and the average over the experimental period was 2 ppm. The Aqua Hort Mini does require quite a high level of conductivity in the supply water to work efficiently and it is suggested that the typical conductivity of 500 uS/cm in the East Malling water was not sufficient. For the year two experiment, a larger machine will be used.

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1.1 Technology transfer

No technology transfer activities were undertaken during the first year of this project.

1.2 References

Goldsworthy A, Whitney H & Morris E. 1999. Biological effects of physically conditioned water. *Water Research* **33**: 1618-1626.

Pedersen L. 2003. Afprøvning af AquaHort. *Gartner Tidende* **32**: 4-5

2. Appendix 1. Details of the pesticides used in experimental treatments

Product	Active ingredient (%)	Rate used	Approval status
Fungex	copper ammonium carbonate (8% w/w)	50 L / 1000 L	Approved
Standon Etridiazole 35	etridiazole (35% w/w)	40 g / m^3	Approved at time of experiment, but since revoked.
Mogeton	quinoclamine (25% w/w)	7.5 kg/ha	Biocide, not approved for use over crops but SOLA application submitted
Aliette 80WG	fosetyl-ammonium (80% w/w)	1 kg / 1000 L	Approved

3. Appendix 2. Nutrient analyses.

a) Effect of increased copper in irrigation water on growing media nutrient content (mg/L).

	Pre-treatment (18/5/06)	Post-treatment (14/9/06)		
		1. Mains water	**2. E Cu water**	**3. Cu feed**
PH	6.52	6.39	6.38	6.69
Chloride	44.3	136.8	154.4	158.1
Phosphorous	11.3	19.5	25.1	27.3
Potassium	100.3	74.0	93.5	92.9
Magnesium	65.4	56.8	54.4	33.9
Calcium	54.3	60.7	54.8	32.7
Sodium	42.4	193.0	177.5	175.5
Ammonia-N	78.4	16.1	10.5	18.5
Nitrate-N	97.8	28.2	36.7	19.3
Sulphate	314.6	622.8	473.6	366.7
Boron	0.32	0.34	0.31	0.34
Copper	**0.11**	**0.10**	**0.16**	**0.14**
Manganese	0.68	0.64	0.27	0.17
Zinc	0.44	0.19	0.17	0.22
Iron	26.69	11.02	12.38`	10.63
Conductivity uS/cm	315	369	331	296

Post-treatment samples were taken from the *Chamaecyapris lawsoniana* 'Elwoodii' *Phytophthora* study.

b) Levels of copper (mg/L) achieved in irrigation water using an Aqua Hart Mini copper ioniser and an enhanced level copper nutrient feed.

Date	**Mains water**	**E Cu water**	**Cu feed water**
18/5/06	0	4.24	0.31
25/5/06	0	0.38	0.14
1/6/06	0.02	0.96	1.10
8/6/06	0.02	2.23	0.98
15/6/06	0	2.33	4.12
22/6/06	0	3.67	4.18
29/6/06	0.03	0.32	1.94
6/7/06	0	1.03	3.80
13/7/06	0	1.84	1.73
20/7/06	0	4.58	3.60
27/7/06	0	1.37	0.32
3/8/06	0	1.18	0.96
17/8/06	0	1.87	1.41
24/8/06	0	2.49	0.70
31/8/06	0	2.36	2.41
7/9/06	0	1.39	1.17
Average		2.01	1.81

4. Appendix 3. Trial plan.

Appendix 3 Trial Plan 2006

Plot	1		2		3		4		5	
Treat	**Untreated**		**CU nutrient feed**		**E Cu**		**biological**		**chemical**	
Plant	**Aquil**	**Prun**	**Cytis**	**Aquil**	**Aquil**	**Cytis**	**Aquil**	**Chama**	**Chama**	**Cytis**
Plant	**Chama**	**Cytis**	**Chama**	**Prun**	**Prun**	**Chama**	**Prun**	**Cytis**	**Prun**	**Aquil**
Plot	6		7		8		9		10	
Treat	**Biological**		**CU nutrient feed**		**Untreated**		**chemical**		**E Cu**	
Plant	**Prun**	**Aquil**	**Cytis**	**Chama**	**Prun**	**Chama**	**Chama**	**Aquil**	**Chama**	**Cytis**
Plant	**Cytis**	**Chama**	**Prun**	**Aquil**	**Cytis**	**Aquil**	**Prun**	**Cytis**	**Prun**	**Aquil**
Plot	11		12		13		14		15	
Treat	**chemical**		**Untreated**		**CU nutrient feed**		**E Cu**		**biological**	
Plant	**Cytis**	**Prun**	**Aquil**	**Chama**	**Chama**	**Cytis**	**Cytis**	**Prun**	**Chama**	**Prun**
Plant	**Chama**	**Aquil**	**Prun**	**Cytis**	**Aquil**	**Prun**	**Chama**	**Aquil**	**Aquil**	**Cytis**
Plot	16		17		18		19		20	
Treat	**Untreated**		**chemical**		**CU nutrient feed**		**biological**		**E Cu**	
Plant	**Prun**	**Aquil**	**Cytis**	**Aquil**	**Prun**	**Chama**	**Chama**	**Cytis**	**Prun**	**Chama**
Plant	**Cytis**	**Chama**	**Chama**	**Prun**	**Cytis**	**Aquil**	**Aquil**	**Prun**	**Aquil**	**Cytis**

Each plot surrounded by a line of *Prunus* as guards

Treat

1 Irrigated with untreated water
2 Irrigated with E Cu water
3 Irrigated with enhanced level copper nutrient feed
4 Industry standard chemical control - untreated water
5 Industry standard biological control - untreated water

Plant / Study

1 *Chamaecyparis* & *Phytophthora*
2 *Aquilegia & Pythium*
3 *Prunus & Pseudomonas*
4 *Cytisus* & liverwort