Project title:	Improving the quality of HNS and roses using irrigation and fertigation management techniques
Project number:	HNS 141
Project leader:	Dr Mark A Else, East Malling Research
Report:	Annual report, March 2008
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Key staff:	Dr Mark A Else Mrs June Taylor Mrs Helen Longbottom Mr Gregory Paternoster
Location of project:	East Malling Research, East Malling, Kent
Project co-ordinators:	David White (Chessum Plants Ltd) David Hooker (Hillier Nurseries)
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Keywords:	Distribution chain, fertigation, HNS, irrigation, quality, retail centre, roses, shelf-life, water. *Cornus alba* 'Elegantissima', *Cotinus coggygria* 'Royal Purple', *Forsythia* × *intermedia* 'Lynwood Gold', *Forsythia* × *intermedia* 'Weekend', *Mahonia* × *media* 'Winter Sun', *Photinia fraserii* 'Red Robin' *Rosa* 'Remember Me', *Rosa* 'Just Joey', *Rosa* 'Arthur Bell' and *Rosa* 'Margaret Merril'

Disclaimer:

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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Organisation

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Contents

GROWER SUMMARY

Headline

- Imposing Regulated Deficit Irrigation (RDI) using drip irrigation to supply 50% or 75% of plant demand for water improved plant quality at market date in *Forsythia* × *intermedia* 'Lynwood Gold'' *Cornus alba* 'Elegantissima' and *Rosa* 'Margaret Merril'. However, **the quality of *Mahonia × media* 'Winter Sun', *Photinia fraserii* 'Red Robin' and *Rosa* 'Arthur Bell' was reduced at market date by RDI.**

Background and expected deliverables

The project aims to improve plant quality of HNS species and containerised rose cultivars using irrigation management techniques during the production cycle. There is much interest in using water more efficiently in the production of HNS and several projects are currently making progress to this end (*e.g.* HNS 97b, HNS 122, and Defra HH3731SHN). In this project, seven HNS species and four rose cultivars have been used to determine the effects of deficit irrigation and fertigation on plant 'quality'.

Deficit irrigation techniques such as Regulated Deficit Irrigation (RDI) replace only a percentage of the water the plant loses *via* transpiration. This saves water and has the potential to modify shoot growth, plant 'robustness', plant habit and visual appeal. Research in other crops suggests that RDI can also improve shelf-life potential by bestowing an increased tolerance to the stresses encountered during distribution and retailing.

There are two aims to this project:

1. To determine the effects of RDI on components of plant quality at the point-of-sale.

2. To determine whether plants previously exposed to RDI during the production cycle are better able to tolerate the stresses encountered during distribution and retailing.

Expected deliverables from this work include:

- Improved crop consistency and uniformity with associated reductions in labour costs
- Improved economic returns by reducing wastage and producing high value 'robust' plants
- The delivery of efficient and sustainable production methods to improve quality and shelf-life of HNS and containerised roses
- More efficient use of water and reduced environmental pollution
- Potentially beneficial effects on scheduling and manipulation of flowering time

Summary of the project and main conclusions

Effects of RDI regimes on plant quality

Irrigation to six HNS species and four rose cultivars was scheduled using the EvapoSensor and EvapoMeter. Well-watered plants received 100% of the daily potential evapotranspiration (ET_p). RDI regimes of 75% and 50% were applied using drip irrigation during the first year of the production cycle. *Mahonia* and *Photinia* were grown under cover to optimise the quality of the foliage; all other species were maintained outside on mypex-covered sand beds. Although frequent and heavy rainfall during the summer reduced the effectiveness of the treatments, sufficient soil drying was imposed to influence plant growth and quality in some species.

The criteria for assessing plant quality in the HNS species and rose cultivars used in the project (see Annual Report 2007) have been developed through consultation with Mr David White (Chessum Plants Ltd) and Mr David Hooker (Hillier Nurseries). In addition to delivering substantial water savings, RDI affected several components of quality in some, but not all, of the species and cultivars tested. The results are summarised below:

RDI improved the quality of ***Forsythia* × *intermedia* 'Lynwood Gold'**:

- Plant height was reduced by up to 25% in RDI-treated plants. Plant spread was unaffected.
- The total number of branches produced during the first year of production was not affected by RDI.
- Time of flowering was not affected by RDI but the shortening of internodes in RDI-treated plants increased the density of flowers per unit length of stem. Therefore, RDI-treated plants appeared more floriferous.

RDI improved the quality of ***Cornus alba* 'Elegantissima'**:

- Plant height and spread were unaffected by RDI.
- Branching potential was improved by RDI.
- If the RDI regime is too severe, leaf reddening and marginal scorch will occur during the first year of production.

RDI improved the quality of ***Rosa* 'Margaret Merril':**

- RDI-50% increased the average thickness of the basal breaks in 'Margaret Merril'. Consequently, the number of strong breaks was increased and the percentage grade-out was improved by RDI-50%.
- The average number of breaks per plant was not affected in RDI-treated 'Margaret Merril'' and 'Just Joey' but was reduced in 'Arthur Bell' and 'Remember Me'.
- RDI reduced the percentage grade-out in 'Remember Me'.
- Internode length (and therefore plant height) was reduced in RDI-treated 'Just Joey' and 'Remember Me'.

RDI did not affect quality of ***Forsythia* × *intermedia* 'Weekend':**

- Plant height and spread was reduced only slightly by RDI.
- In contrast to results from 2007, RDI did not reduce branching potential.

RDI reduced the quality of ***Mahonia × media* 'Winter Sun'**:

- Plant height was reduced slightly by RDI-50%, with spreads unaffected.
- RDI-50% induced leaf reddening that reduced overall quality (Figure GS1).
- Time of flowering was delayed by up to three weeks by the RDI-50% regime. The average number of racemes (flower stalks) per plant was not affected.

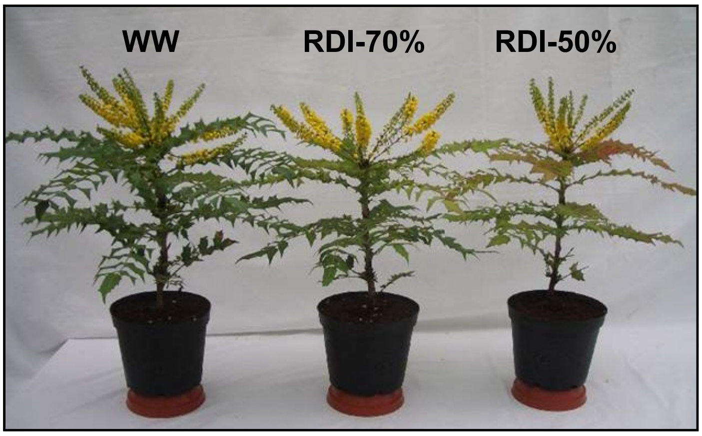


Figure GS1. RDI-50% reduced plant height but promoted leaf reddening

RDI reduced the quality of ***Photinia fraserii* 'Red Robin':**

- RDI regimes reduced plant height before all plants were pruned in September 2007.
- The number of breaks following pruning was reduced by 20% in RDI-treated plants.
- RDI imposed during 2007 reduced the production of new shoots in March 2008.

Effects of RDI regimes on shelf-life potential

The potentially beneficial effects of RDI on shelf-life potential will be determined for the four Rose cultivars and for *Photinia* and *Cornus* during April-June 2008. Containerised roses previously exposed to RDI will be dispatched from EMR in a container lorry and transported for several days to replicate the conditions encountered during distribution.

The maximum or minimum substrate moisture contents (SMC) values identified during visits to retail centres in 2007 (see below) will then be imposed during a six-week shelf-life test in May-June 2008. The potentially beneficial effects of previously exposing plants to RDI on shelf-life potential will be determined. Environmental conditions encountered during the peak sales period for *Forsythia* spp. (March-April) and *Mahonia*

(September - November) are unlikely to affect plant quality so shelf-life is generally not an issue for these species.

Conditions during transport

The range of temperatures and relative humidities (RH) inside different types of container lorry used to transport dormant-stage roses was determined in February 2007. Data loggers were placed inside a ‘box’ container lorry, a ‘curtained’ container lorry and a ‘refrigerated’ container lorry with the fans on but the cooling turned off. Air temperature and RH was logged every 30 minutes.

- RH values fell to 60% during the day in the ‘curtained’ container lorry but remained at 100% in the ‘box’ container lorry throughout the three days of measurements. In the ‘refrigerated’ lorry, diurnal changes in RH ranged from 80-100%.

- Temperature fluctuations between night and day were greatest in the ‘curtained’ container lorry, followed by the ‘box’ container lorry.

The conditions encountered during transport at the half-growth stage (June 2007) were also determined.

- RH values fell to 50% during the day in the ‘curtained’ container lorry. RH remained between 80 and 100% in the ‘refrigerated’ container lorry throughout the eight days of measurements.

- Diurnal changes in temperature ranged from 10-30 °C in the ‘curtained’ container lorry while temperature was maintained between 13 °C and 20 °C in the ‘refrigerated’ container lorry.

The impact of high RH encountered during transport on the subsequent development of disease such as downy mildew at the half- and full-growth stages has not yet been determined. Optimum conditions for the germination of downy mildew spores are 18 °C and greater than 85% RH, precisely the conditions measured in the ‘refrigerated’ container lorry. Although growers strive to ensure that plants are ’clean’ when they leave the nursery, the higher temperatures and lower RH values in the ‘curtained’ container lorry may reduce disease pressure during the subsequent retailing phase if spores are present at the time of dispatch. The extent of ethylene accumulation inside the different container lorries during transport and its impact on plant quality at the half-and full-growth stages will also be determined in 2008.

Conditions during retailing

Visits to seven retail outlets were made throughout 2007 during the peak sales period of the chosen species. Measurements were made at Burston Nurseries, Chessum Plants Ltd, Harkness Roses and four Wyevale Garden Centres (Hitchin, Willesborough, Canterbury, Paddock Wood). Irrigation was applied using overhead sprinklers at all sites but there was considerable variation in the timing and frequency of irrigation events. Plant and pot weights, SMC, E.C. levels, leaf chlorophyll content (a proxy measure of leaf nitrogen status) and transpiration rate were determined on each occasion. Substrate moisture content was chosen as the most reliable criterion for assessing the degree of stress encountered during retailing. Data loggers were placed at some sites to track air temperatures and RH during May, June and July.

- Measurements made at seven retail centres during May, June and July identified the maximum and minimum SMC that each species encountered (Table GS1). These SMC values will be imposed during shelf-life tests in May-June 2008.

Table GS1. Maximum and minimum substrate moisture content recorded for Rose and several HNS species during visits to retail centres during May, June and July 2007.

Species	Substrate moisture content ($m^3 m^{-3}$)	
	Maximum	Minimum
Rosa - Hybrid Tea	0.54	0.21
Rosa - Floribunda	0.55	0.21
Cotinus coggygria	0.58	0.14
Photinia fraserii	0.51	0.34
Cornus alba	0.46	0.21

- The degree of soil drying measured at some sites was similar to that achieved during the RDI experiments carried out at EMR. However, the sporadic and unregulated nature of this root-zone stress during retailing often reduced plant quality. *Cornus* was especially prone to inadequate watering and severe leaf desiccation greatly reduced plant quality at some sites (Figure GS2).

Figure GS2. The deterioration in quality of *Cornus* over six weeks at a retail centre during summer 2007 due to inadequate watering

- Frequent and heavy rainfall combined with inefficient irrigation scheduling resulted in over-wet conditions at several sites. Plant quality at these sites gradually deteriorated over the measurement period.

- There is scope to minimise the deterioration in plant quality and reduce the associated volume of wastage during retailing by improving the precision and scheduling of irrigation.

Financial benefits

Improving irrigation scheduling and imposing RDI will reduce water use and improve plant quality, uniformity and shelf-life potential in some HNS species and rose cultivars. Possible financial benefits resulting from these treatment effects, and the associated reductions in labour costs and waste, will be discussed with industry representatives and retailers during the final year of this project.

Action points for growers

- Deficit irrigation can improve overall quality in *Forsythia* × *intermedia* 'Lynwood Gold' and *Cornus alba* 'Elegantissima'.

- Using RDI can increase the thickness of basal breaks and improve the percentage grade-out in some 'shy breaking' rose cultivars such as 'Margaret Merril'.

- Water savings of up to 50% can be achieved by using RDI without reducing the quality of *Forsythia* × *intermedia* 'Weekend'.

- RDI should not be used on *Mahonia* and *Photinia* as plant quality will be reduced.

- *Photinia* should be well-watered when pruned in September to maximise the number of new shoots as even mild soil drying can limit shoot production.

- RDI can be used to improve the quality of some outdoor crops even in seasons with heavy rainfall.

- *Cornus* is particularly prone to leaf desiccation caused by inadequate or inefficient irrigation; this problem is exacerbated if freely-draining compost is used. Growers may consider using composts with greater water-retaining properties for 'thirsty' species.

- Avoiding prolonged periods of high RH during transport may help to reduce disease pressure on roses during subsequent retailing at the half- and full-growth stages.

- During discussions with retailers, growers should continue to emphasise the importance of good irrigation scheduling if high plant quality is to be maintained during retailing.

- Campaigns to improve consumer awareness of the factors that contribute to good quality may help to reverse the recent fall in sales of containerised roses.

SCIENCE SECTION

Introduction

The project aims to improve plant quality of HNS species and containerised rose cultivars using irrigation and fertigation management techniques during the production cycle. These deliverables will assist the HDC in fulfilling the objectives outlined in the HNS Strategy document where enhancing production efficiency and improving plant quality have been identified as key targets.

There is currently much interest in using water more efficiently during the production of HNS and several key projects are making good progress towards this goal (*e.g.* HNS 97b, Defra HH3731SHN). HNS growers also recognise that good management of irrigation will help to reduce labour costs associated with hand-watering and those costs associated with grading of plants for marketing; work in HNS 97 identified that uneven water application was a major cause of lack of uniformity.

One of the objectives of HNS 97b (Water LINK II) is to establish whether irrigation scheduling can be implemented successfully in the commercial production of several HNS species. How this might be best achieved using the existing irrigation systems on commercial nurseries has recently been addressed on the East Malling Water Centre (EMWC) in HNS 122. The project highlighted the issue of non-uniformity of water application and the repercussions for plant quality. Complete uniformity was difficult to obtain under overhead irrigation, particularly outdoors. The use of a gantry overhead irrigation system (installed in HNS 122a) greatly increased irrigation uniformity, and seemed to offer several advantages over conventional overhead systems (HNS 122 – Final Report). However, these potential advantages need to be verified and quantified so that the large capital investment needed for this approach can be justified. In addition, the potential of deficit irrigation to deliver further water savings into the HNS sector is being determined in HNS 97b.

Deficit irrigation involves replacing only a percentage of the water the plant loses *via* transpiration. The aim is to impose a very gradual soil drying treatment to stimulate the production of root-sourced chemical signals (*e.g*. plant hormones). These signals are then exported in the transpiration stream to the shoots where they can modify shoot growth and stomatal behaviour. Many of these chemical signals are also likely to influence plant 'robustness', plant habit, time of flowering and, as a result, visual appeal.

Our work in Defra funded project HH3609TX [Partial rootzone drying (PRD): delivering water saving with sustained high quality yield into UK horticulture] suggests that Regulated Deficit Irrigation (RDI) can improve the shelf-life potential of protected crops such as poinsettia. Leaf and bract drop were reduced by 50% and 90% respectively, during a six-week home-life test. To simulate conditions encountered during distribution and retailing, plants were held at 10 °C for 12 h, returned to room temperature and left sleeved for a week without watering to simulate conditions in the retail environment. Only when the plants encounter these sorts of stresses do the added benefits of deficit irrigation become apparent.

The aims of this project are two-fold. Firstly, we will determine the effects of deficit irrigation on plant quality at simulated market date. The individual components (*e.g.* height, spread, branching framework) that determine overall plant quality will vary between different species and the perception of these attributes can also be fairly subjective. Amongst different HNS growers, the perception of quality will necessarily be influenced by individual retailers' plant specifications. The perception of plant quality by the consumer may also vary widely and may not reflect the opinions of the growers and retailers. Thus, our assessments must incorporate these different views if the effects of deficit irrigation on plant quality are to be determined accurately and reproducibly.

Secondly, we will determine whether plants previously exposed to RDI during the production cycle are better able to tolerate the stresses encountered during distribution and retailing. Conditions during distribution can have a marked effect on rose quality and susceptibility to disease during the subsequent retail phase. The on-going globalisation of the UK horticulture industry will exacerbate any existing problems associated with transportation as UK growers and retailers increasingly source plant material from overseas. Standards of plant care can vary widely between retailers and unfavourable conditions during this period can markedly limit plant quality and subsequent garden performance, as highlighted recently in the HDC training DVD on Ornamental Plant Care. Increased tolerance to these stresses as a result of deficit irrigation treatments such as Regulated Deficit Irrigation (RDI) would help to reduce wastage in-store and also benefit consumers.

Materials and Methods

Objective 1: To develop criteria for the assessment of plant quality

The quality criteria for the *Rosa* cultivars were developed by David White and his colleagues at Chessum Plants Ltd (see Year 1 Annual Report). Sixteen containerised roses of varying quality of four cultivars (two Hybrid T's and two Floribunda) were scored for quality by five 'experts'. Scoring was based on a five-point scale with 1 representing very poor quality and 5 representing excellent quality. The roses were transported to EMR in a 'curtained' container lorry in the last week of March 2007. The scoring was then repeated by an EMR 'consumer' panel consisting of twenty individuals (horticulturists and non-horticulturists). The consistency with which the 'consumers' scored each rose cultivar on consecutive days was also assessed. Different plants of the same score were used on each day so that the 'consumer' scores on the second day weren't influenced by the recognition of individual plants from the previous day's assessments. Scores between the two groups were compared to determine whether the perception of plant quality at point-of-sale differed between 'experts' and 'consumers'. A correlation value of +1 indicated perfect agreement, 0 equals no agreement, -1 implied complete disagreement.

Objective 2: To define and duplicate conditions encountered during retail transport and shelf-life.

Data loggers ('TinyTag Plus 2') were placed inside three delivery lorries loaded with Danish Trolleys each carrying 128 containerised roses at the dormant stage of growth. Air temperature and relative humidity (RH) during distribution in a 'curtained' container, a 'box' container and a 'refrigerated' container (cooling turned off) were recorded. The lorries were dispatched from Chessum Plants Ltd on 22 February 2007 and two returned to the nursery on 24 February and on 8 March after completing deliveries to retailers throughout the country. The logger from the refrigerated lorry was finally retrieved in July 2007. Conditions during transit were also logged in June 2007 when plants at the half-growth stage were being transported.

Visits to seven retail outlets were made on several occasions in May, June and July 2007 during the peak sales period of the chosen species. Measurements were made at Burston Nurseries, Chessum Plants, Harkness Roses and four Wyevale Garden Centres (Hitchin, Willesborough, Canterbury, Paddock Wood). Irrigation was applied using overhead sprinklers at all sites but there was considerable variation in the timing and frequency of irrigation events. Plant and pot weights, substrate moisture contents (SMC), E.C. levels, leaf chlorophyll content (a proxy measure of leaf nitrogen status) and transpiration rate were determined on each occasion. The number of species measured during each visit was dictated by the range of plants available at that time but up to ten replicate plants were measured when possible. 'TinyTag 2' data loggers were placed at some sites to track air temperatures and relative humidity during May, June and July.

Objective 3: To determine the impact of irrigation and fertigation regimes on quality and shelf-life.

Plant material

Liners of *Forsythia* × *intermedia* 'Lynwood Gold', *Forsythia* × *intermedia* 'Weekend', *Cornus alba* 'Elegantissima', *Mahonia* × *media* 'Winter Sun', and *Photinia fraserii* 'Red

Robin' in 9cm pots were sourced from New Place Nurseries Ltd. All HNS species were dispatched in March 2007 and were potted on into 3 L pots containing substrate sourced from New Place Nurseries Ltd. All plants were hand-watered immediately after potting and the 'Lynwood Gold', 'Weekend' and 'Elegantissima' were placed out on mypex-covered sand beds at EMR where they were left to establish for four weeks. *Mahonia* and *Photinia* were maintained in a polytunnel on the EMR Water Centre to optimise the condition of the foliage at simulated market date. Empot carriers were used to ensure that all plants remained upright throughout the experiments; plants were spaced at 30 cm.

Maiden bushes of *Rosa* 'Remember Me', *Rosa* 'Just Joey', *Rosa* 'Arthur Bell' and *Rosa* 'Margaret Merrill' were sourced from Chessum Plants Ltd and were delivered to EMR in April 2007. The bare-rooted stocks were potted into 3 L pots containing compost sourced from Chessum Plants Ltd. Again, all pots were maintained on mypex-covered sand beds and hand-watered during a 4-week establishment period. Rootstock suckers were removed as and when necessary.

Irrigation application and scheduling

Each pot was irrigated using pressure-compensated, non-leakage drippers (TORO NGE 2, 3, or 4 L h^{-1}, City Irrigation Ltd, UK) each connected to a lace (PVC tubing, 4 mm i.d.) and a pot stake. Dripper outputs were tested prior to the experiment to ensure an accuracy of within 10%. Drippers were placed in the middle of each pot to try to ensure an even application of water. The timing and duration of irrigation events was scheduled using Galcon DC-4S controllers (Field (GB) Ltd, UK) connected to a manifold housing either two or four DC-1S ¾" valves. Each HNS species or *Rosa* cultivar was irrigated using separate irrigation lines so that volumes could be adjusted precisely to match demand throughout the experiment.

Irrigation treatments were applied as a percentage of potential evapotranspiration (ET_p). ET_p values were obtained using an SKTS 500/PRT Evaposensor and SEM 550 Evapometer (Skye Instruments Limited, Llandrindod Wells, Powys, UK). The Evaposensor was positioned amongst the experimental plants and maintained at canopy height. The irrigation time (t) required to return the plants to pot capacity after a given period of time was calculated using the equation $t = E_{acc.} \times F$, where E_{acc} is the Evapometer output for that period. A factor (F) was recalculated regularly to adjust for changes in canopy area and environmental conditions; where W is the mean weight loss from a well-watered plant (n=6) over 24 h, and E_{acc} is the Evapometer output over the same period, F was calculated as

F= W

E_{acc}

F was calculated for each HNS species or *Rosa* cultivar separately. Irrigation was applied three times daily (08:00, 12:00 and 17:00) to minimise the risk of over-watering or run-off from the pots. Each event replaced the relevant percentage of ET_p recorded since the previous irrigation.

During the calculation of F, it is essential that water loss is not restricted by stomatal closure induced by temporary soil drying in the supposedly well-watered plants. This scenario would lead to erroneous F values that would continue to decrease despite increases in leaf area and result in deficit irrigation being applied in the control well-watered treatment. To circumvent these problems in 2007, we included 12 plants in each experiment that were used solely to calculate F. In addition to the scheduled irrigation, these plants were topped-up with hand watering to ensure that the compost was kept moist.

Experimental design and irrigation regimes

In a series of three experiments, plants were arranged on the sand beds in randomised block designs that were generated using Genstat. For each treatment, there were 12 replicates for the HNS species tested and 9 replicates for each rose cultivar. Three treatments were applied: a well-watered (WW) control given 100% ET_p, and two RDI treatments of 75% and 50% ET_p. Additional plants that were used to calculate F were interspersed throughout the experimental plants.

Experiment 1: Treatments were applied to *Forsythia × intermedia* 'Lynwood Gold', *Forsythia × intermedia* 'Weekend' and *Cornus alba* ‘Elegantissima’ on 2 May 2007 (Day 0) until 8 October 2007 (Day 159).

Experiment 2: Treatments were applied to *Mahonia × media* ‘Winter Sun' and *Photinia fraserii* 'Red Robin’ from 2 May (Day 0) until 8 October 2007 (Day 159).

Experiment 3: Treatments were applied to *Rosa* cultivars ‘Remember Me’, ‘Just Joey’, ‘Arthur Bell’ and ‘Margaret Merril’ from 8 May (Day 0) until 8 October 2007 (Day 153).

Monitoring RDI regimes

In each of the three experiments, plant-and-pot weights were determined twice weekly throughout the experiment using a portable balance (ScoutPro 4000, Ohaus UK Ltd, UK). The substrate volumetric moisture content (SMC), E.C. levels and soil temperature in each pot was determined using a Delta T WET sensor and Delta T HH2 Moisture meter (Delta T Devices, UK), which was calibrated for the compost used. Measurements were made through holes drilled mid-way up both sides of the pots. These measurements helped to determine whether the RDI regimes were being applied effectively in each species or cultivar tested.

Following significant rainfall events during the season, irrigation was suspended until the pot weights had returned to the values recorded at the last measurement date. At the end of each experiment (October 2007), all RDI-treated plants were gradually re-watered to pot capacity and plants were left to over-winter on the sand beds.

Components of plant quality

In experiments one and two, plant heights and spreads, and the numbers of new branches produced were measured at intervals throughout the growing season (June-October 2007) and again at the end of the dormant season (March 2008). In experiment three, the numbers of basal breaks were recorded during the first and second growth flushes (May-July 2007) and again at the end of the dormant season (March 2008). Since roses are routinely dead-headed, measuring the effects of RDI on stem height would not be appropriate. Instead, the lengths of the internodes on one stem were measured below 15 cm stem height and the average internode length per rose bush calculated.

An assessment of the components that contribute to plant quality in each species or cultivar (*e.g.* height, spread, number of branches, number of breaks, number of flower spikes) were made immediately prior to the simulated market date for each species.

Objective 4: To identify underlying mechanisms and develop strategies to improve quality

Ethylene production rates of newly-formed shoots excised from three *Rosa* cultivars were measured by head space analysis using a gas chromatogram (GC) fitted with a flame ionisation detector (FID). The effect of increasing ethylene concentrations on the abscission of new shoots is currently being determined. These tests will be repeated at the half-growth stage. This work will identify the critical ambient ethylene thresholds that must be avoided during distribution and retailing if plant quality is to be maintained.

Results

Objective 1

Perception of quality: 'Expert' versus 'Consumer'

Correlation analysis was used to compare the 'expert' score to scores given by a 'consumer' group, consisting of 20 horticulturists and non-horticulturists from the EMR site. A correlation value of +1 indicates perfect agreement, 0 equals no agreement, -1 implies complete disagreement between the 'expert' and 'consumer' scores. For example, when assessing the quality of 'Abbeyfield Rose', over half of the 'consumers' agreed strongly with the experts on the first day of scoring (Figure 1). However, there was only a slight to fair agreement with the 'expert' scores from one third of the panel. On the second day of assessment, the average correlation value was 0.92 (±0.02) indicating a near-perfect correlation between experts and 'consumers'. The correlation between 'expert' and 'consumer' was generally moderate to strong for most *Rosa* cultivates tested, indicating that 'consumers' sought many of the same quality attributes as the 'experts.' The most frequently expressed concern from the 'consumer' group was the planting depth; some 'consumers' preferred the graft union to be visible above the compost while others gave higher scores to plants in which the graft union was buried. The consistency of the 'consumer' scoring on consecutive days varied with cultivar, which underlines the subjective way in which some 'consumers' gauge plant quality.

Objective 2

Conditions encountered during distribution

Conditions in three different types of container lorry were compared during the distribution of dormant-stage roses in February 2007 (Figure 2). In the 'box' container, temperatures ranged from 7 to 15 °C and RH quickly rose to 100% and was maintained at this level over the transport period (Figure 2A). Temperatures were similar in the 'curtained' container lorry but RH fell to 60% during the day before returning to 100% during the evening, night and early morning (Figure 2B). In the 'refrigerated' lorry, the fans were on but the cooling was turned off and so temperatures were maintained within a narrow range (7-11 °C); RH ranged from 80-100% (Figure 2C).

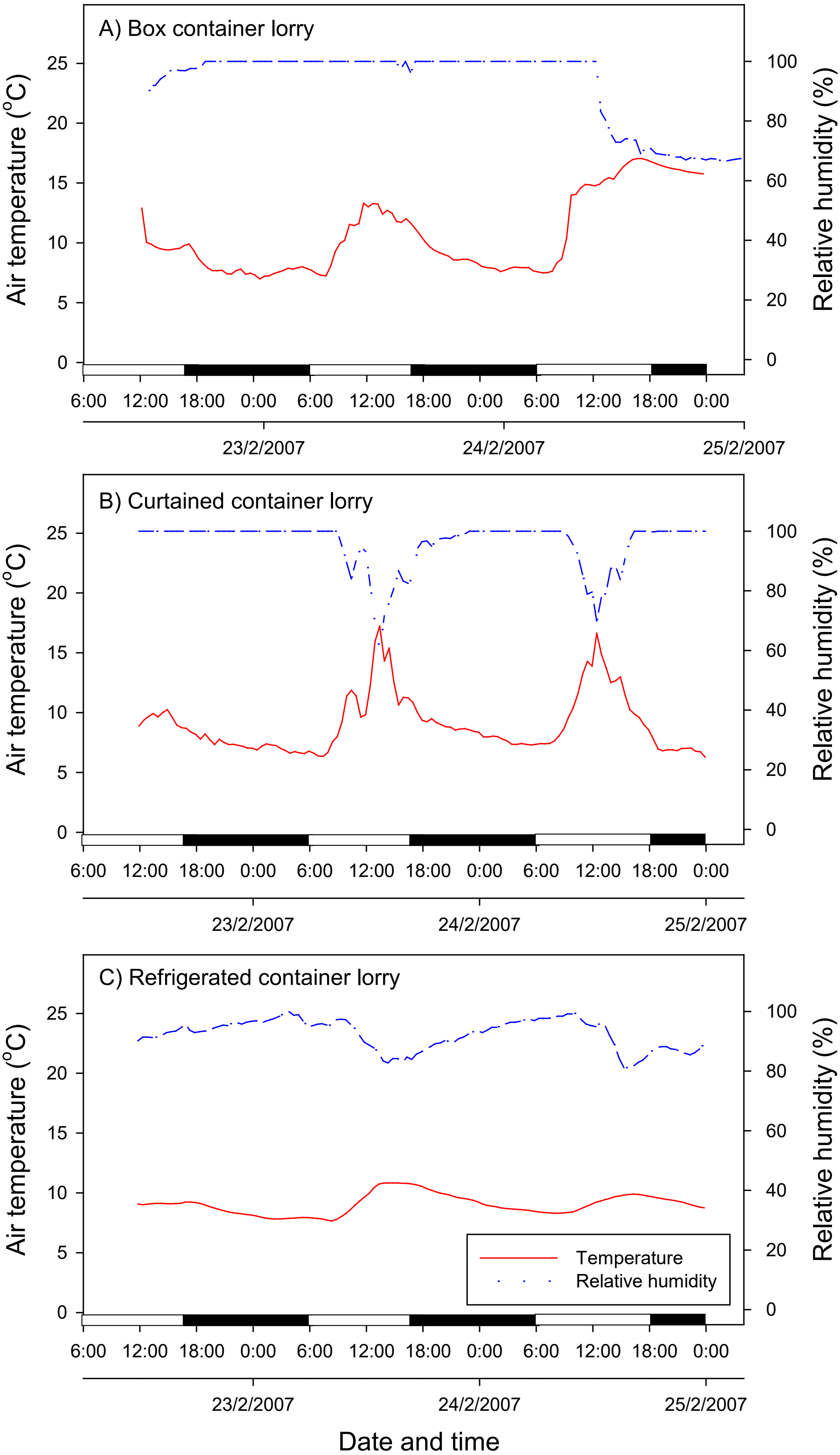


Figure 2. Air temperature and relative humidity inside A) a 'box' container lorry, B) a 'curtained' container lorry, and C) a 'refrigerated' container lorry during the distribution of dormant-stage roses in February 2007.

temperatures reached 30 °C and RH fell to 45% inside the 'curtained' container lorry (Figure 3A). The diurnal fluctuations in temperature and RH were much more limited in the 'refrigerated' container lorry; the cooling maintained the temperature between 12-20°C and RH fell briefly below 80% on only five occasions (Figure 3B).

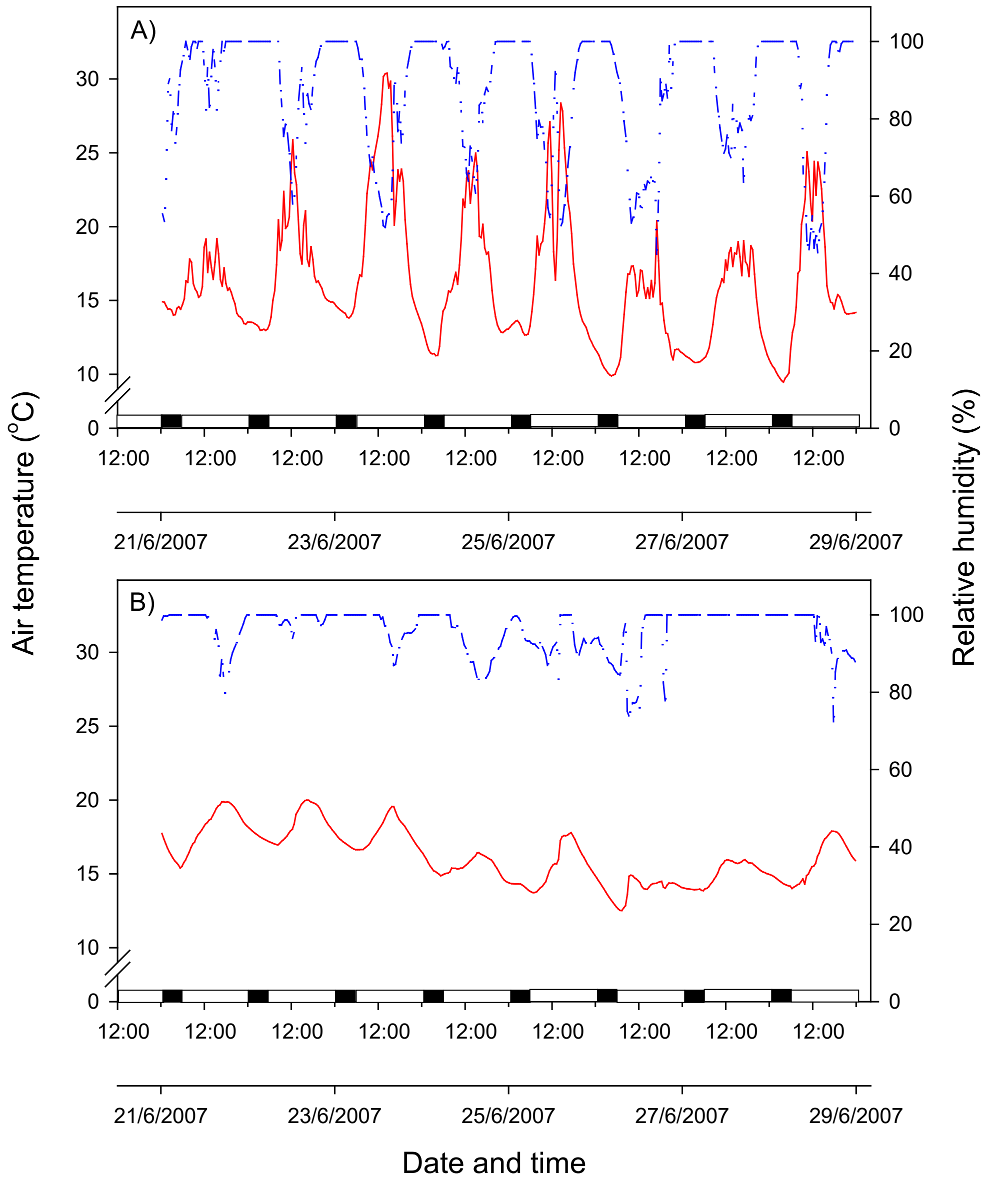
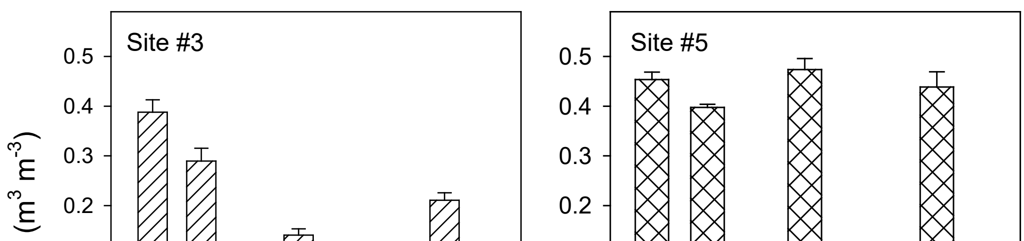


Figure 3. Air temperature and relative humidity inside A) a 'curtained' container lorry and B) a 'refrigerated' container lorry during the distribution of roses at the half-growth stage.

reliable criterion for assessing the degree of stress encountered during retailing. Two measurements were made at opposite sides of a pot and the mean SMC determined. The large differences in the degree of soil drying between sites (Figures 4 – 7) suggested considerable variation in the efficiency and precision of irrigation at the different retail



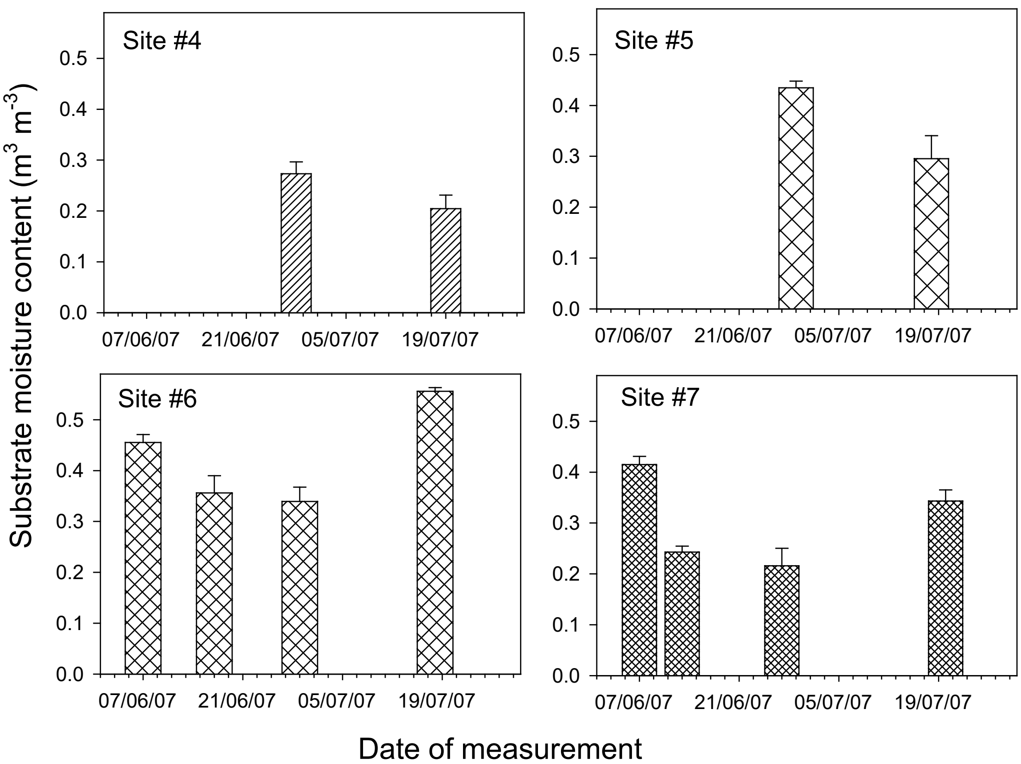
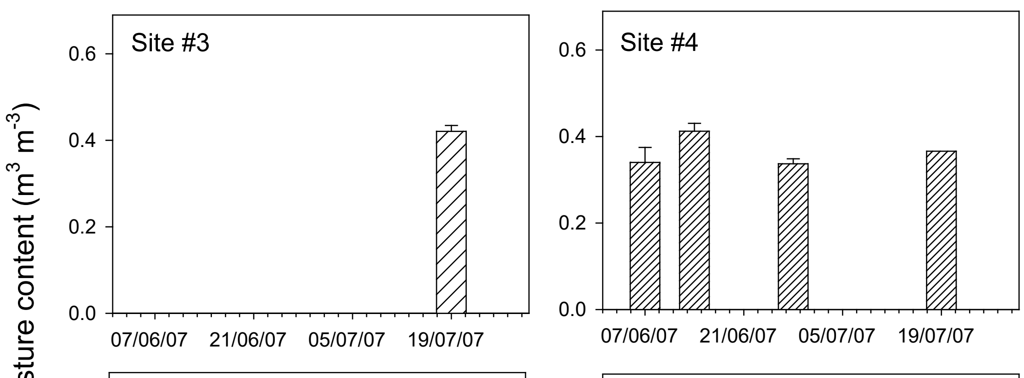
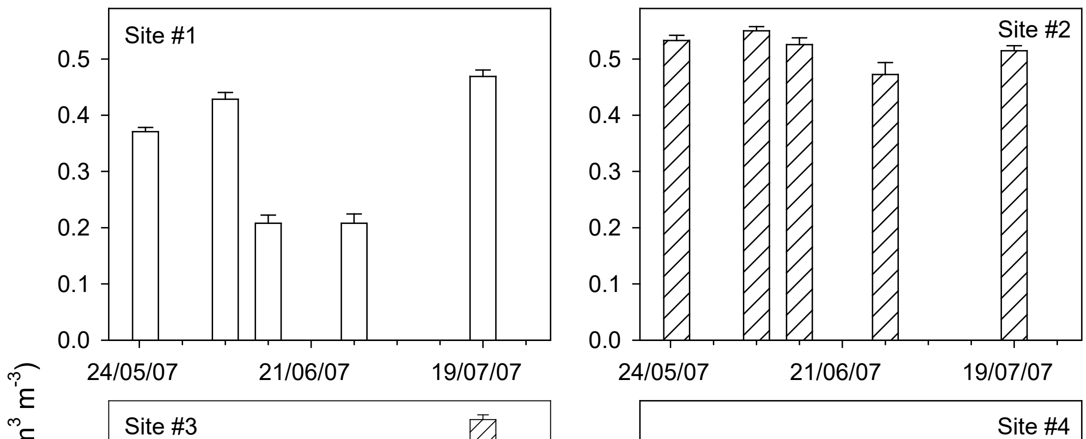


Figure 5. Substrate moisture contents of potted *Cornus alba* measured at four retail centres;



The maximum and minimum SMC for each species have been determined based on the measurements made at the retail centres in 2007 (Table GS 1). These values will be used in experiments at EMR to determine whether plants previously exposed to RDI during the production cycle have an increased tolerance to the environmental conditions encountered during retailing. These shelf-life tests will be carried out during May and June 2008.

The effects of these stresses on plant quality over June and July were also assessed. The extent of the reductions in quality depended on species. For example, severe soil moisture deficits developed in *Cotinus coggygria* but quality was not visibly reduced in these plants (Figure 8). In contrast, the cumulative effect of ineffective irrigation of *Cornus alba* resulted in extensive soil drying (< 0.21 m^3 m^{-3}) at some sites (*e.g.* site 7 [Figure 5]). These lighter pots were increasingly prone to being blown over which reduced further the efficiency of the overhead irrigation. After several weeks, severe leaf desiccation was observed at several sites, greatly reducing the marketability of these plants (Figure 9A and B). At site #6, pots containing *Cornus* spp. were placed in a wooden lattice to prevent them being blown over and irrigation was generally sufficient to prevent excessive soil drying. Consequently, these plants remained in good condition throughout the 6-week assessment period (Figure 9C).



The extent of the deterioration in the quality of containerised roses also varied greatly at the different retail centres. Frequent irrigation events applied during the evening and early morning may have contributed to the decrease in the quality of roses at three of the retail centres. Plants were frequently standing in water and SMC values were often high (> 0.5 m^3 m^{-3}) indicating over-wet compost (Figure 10). The development of black spot and downy mildew was particularly severe under these conditions (Figure 11). In contrast, the overall quality of containerised roses at retail sites where irrigation was scheduled effectively and applied during the early morning (*e.g.* site #2) was maintained throughout the measurement period (Figure 11).

Site #3

Site #5

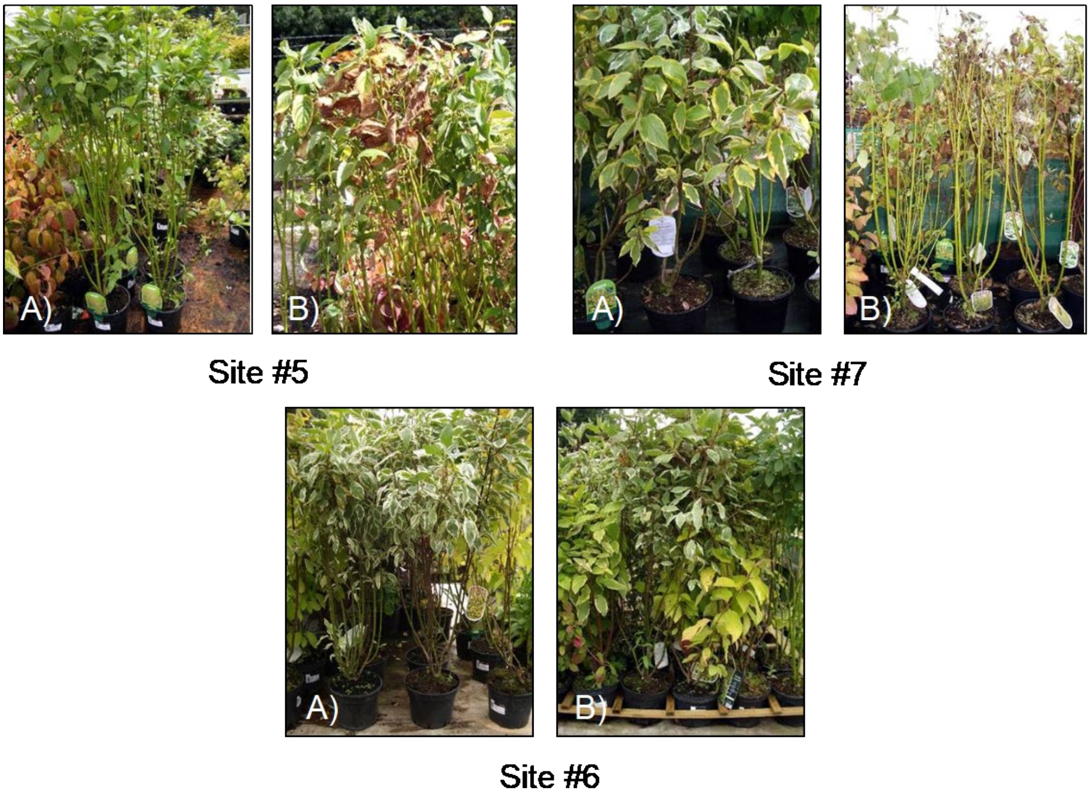
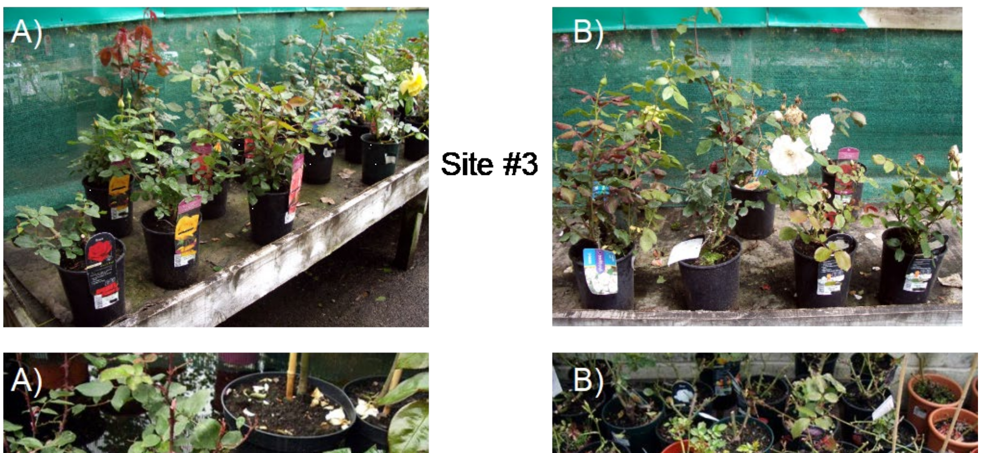


Figure 9. Examples of *Cornus alba spp* at three different retail centres. At each site, photo A) was taken during the first week of June while photo B) was taken in the third week of July.



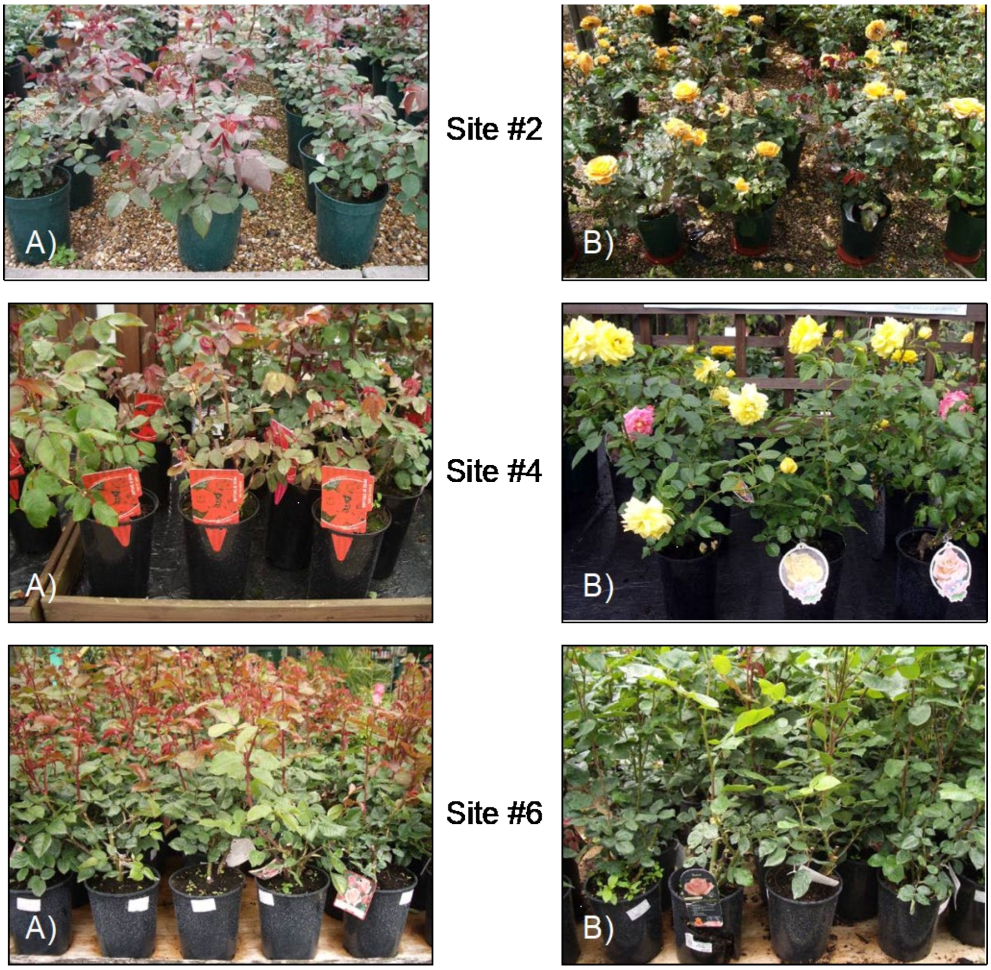


Figure 11. Examples of good quality *Rosa* cultivars available throughout the summer at three different retail centres. At each site, photo A) was taken during the first week of June while photo B) was taken in the third week of July.

Objective 3

Experiment 1

Imposition of RDI

The RDI regimes were first imposed on 2 May 2007. The plant-and-pot weights of the 75% and 50% RDI-treated *Forsythia × intermedia* 'Lynwood Gold' plants decreased gradually over the following three days but then returned to WW values following heavy rain during the first weeks of May (Figure 12A). Treatment differences were gradually re-established during June until a further bout of rainfall increased pot weights again. This pattern was repeated throughout July and August until September when large treatment differences developed in the absence of significant rainfall (Figure 12A). The SMC values confirmed that mild deficit treatments (> 0.2 m^3 m^{-3}) were being applied throughout much of the experiment; transient increases in SMC were also evident following heavy rain (Figure 12B).

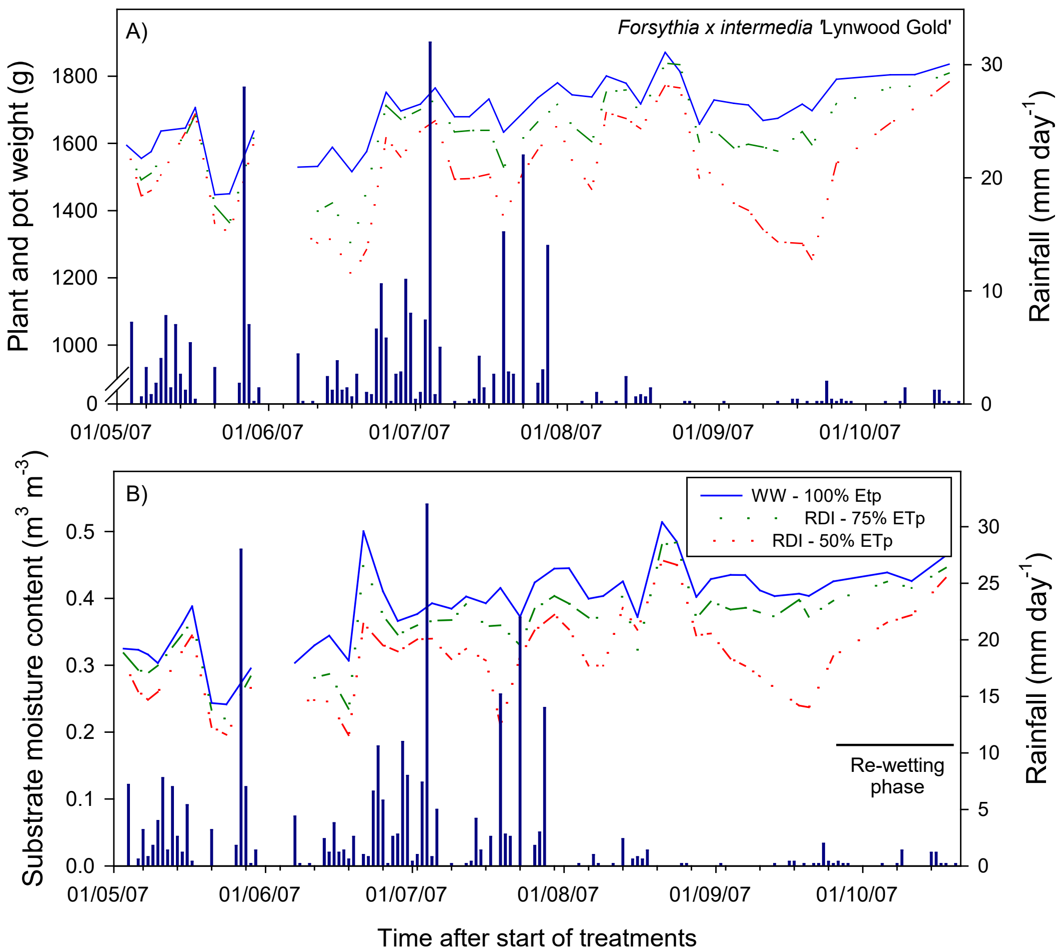


Figure 12. The effects of two RDI regimes imposed on *Forsythia × intermedia* 'Lynwood Gold' during May to October 2007 on A) plant-and-pot weights and B) substrate moisture content. Irrigation was scheduled using the EvapoSensor; well-watered plants received 100% of the daily potential evapotranspiration (ET_p); RDI-treated plants received 75% or 50% of that volume. Results are means of 12 replicate plants. Daily rainfall throughout this period is also presented.

Differences between treatments were gradually reduced during the re-wetting phase in October 2007. The effects of RDI on patterns of plant-and-pot weight loss and SMC over the experiment in *Forsythia* × *intermedia* 'Weekend' were similar to those described above for *Forsythia* × *intermedia* 'Lynwood Gold' except that more severe deficits developed in both the 75% and 50% RDI regimes throughout the first two weeks in June (data not shown).

Mild water deficits developed in both the 75% and 50% RDI-treated *Cornus alba* but despite frequent calculations of F, SMC values were often fairly low in the well-watered plants (Figure 13). Consequently, there was very little difference in the degree of stress imposed between the WW and the RDI-75% regime. Perhaps not surprisingly, whole-plant transpiration rates measured during the middle of the production season were not reduced by the RDI-75% regime, although *E* was significantly lowered in RDI-50% plants compared to well-watered values (Table 1). Rates of water loss in both *Forsythia* species were also reduced by the RDI-50% treatment (Table 1).

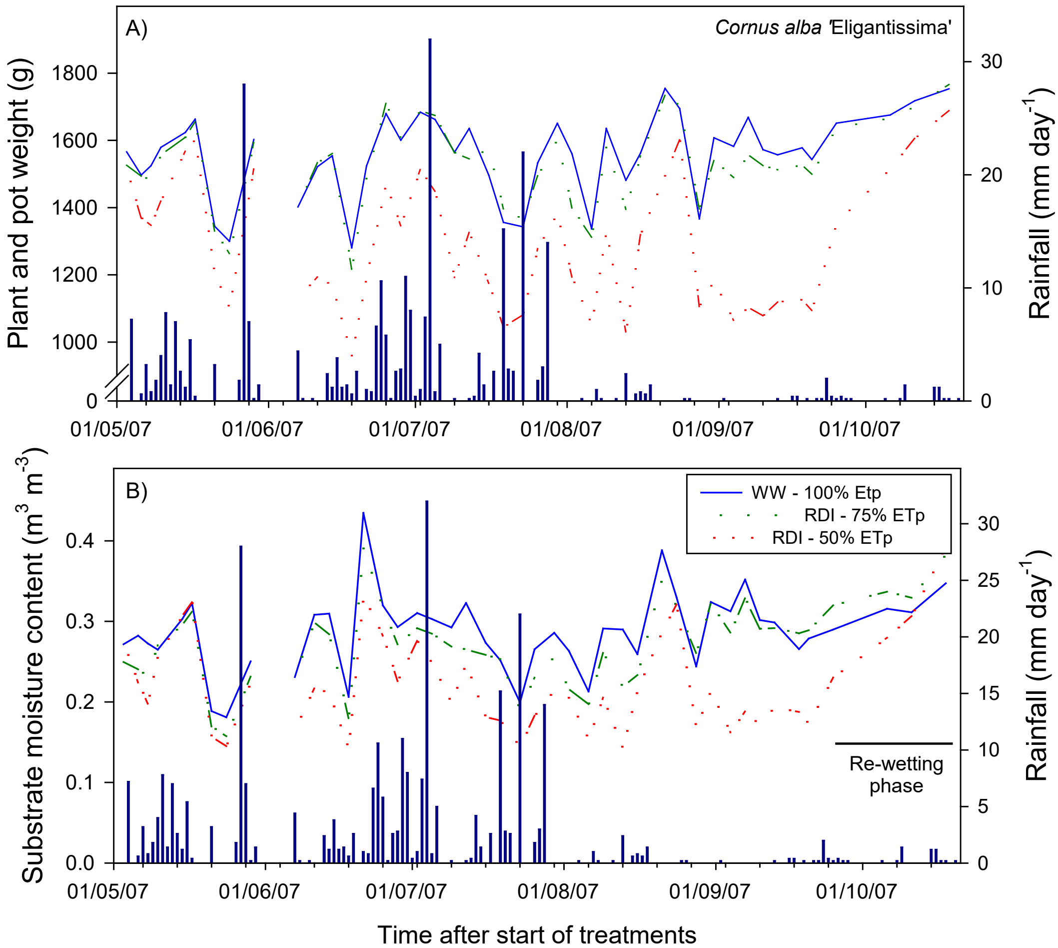


Figure 13. The effects of two RDI regimes on A) plant-and-pot weights and B) substrate moisture content imposed on *Cornus alba* 'Elegantissima' during May to October 2007. Results are means of 12 replicate plants. Daily rainfall throughout this period is also presented.

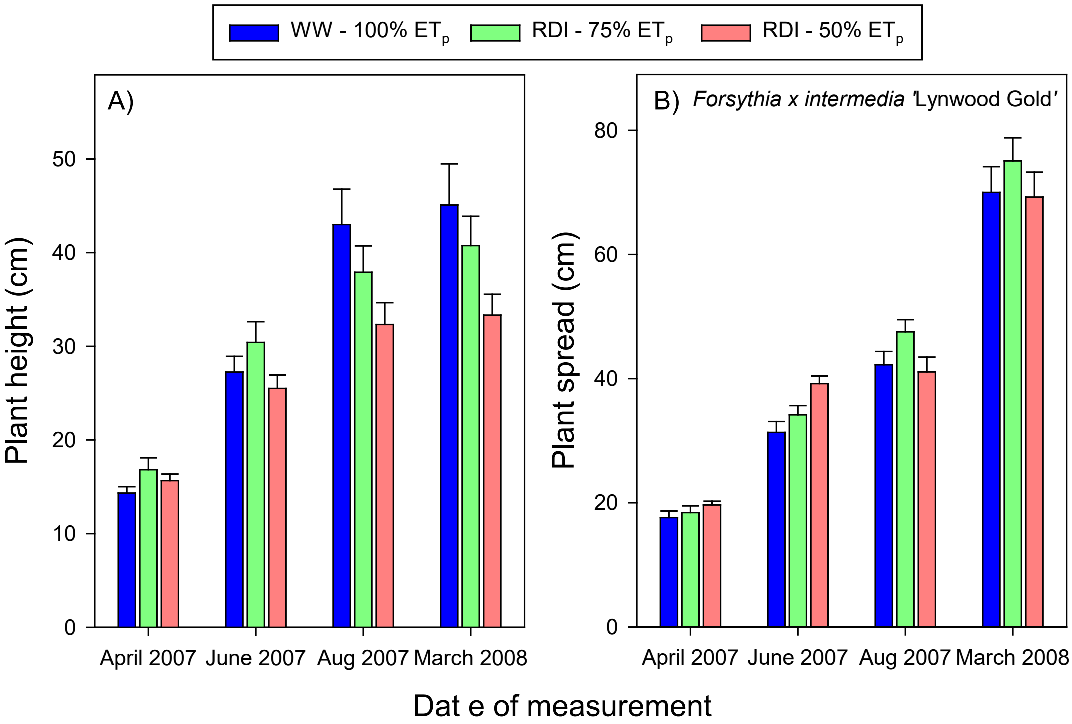


Figure 14. Effects of RDI on A) plant height and B) plant spread in *Forsythia* × *intermedia* 'Lynwood Gold'. Results are means of 12 replicate plants, with associated standard error bars.

Effects of RDI on components of plant quality

As expected, the more compact, 'bushier' cultivar of *Forsythia* ('Weekend') had 50% more branches than the more traditional 'upright' cultivar 'Lynwood Gold' (Table 2). However, branch production in both *Forsythia* 'Lynwood Gold' and 'Weekend' was not affected by RDI at simulated market date (Table 2). In contrast, branch production in *Cornus alba* was increased by the RDI-50% regime compared to well-watered counterparts (Table 2). The increased branching potential help to improve the overall aesthetic value of these plants.

Table 2. Effects of RDI on the number of branches in *Cornus alba* 'Elegantissima', *Forsythia* × *intermedia* 'Lynwood Gold' and *Forsythia* × *intermedia* 'Weekend' during the first year of production. Results are means of six replicate plants with associated standard errors.

Species	Number of branches Irrigation regime (% of ET_p)		
	100%	75%	50%
Cornus alba	14.0 ± 1.4	14.7 ± 2.2	16.8 ± 1.1
F. 'Lynwood Gold'	10.0 ± 1.8	12.0 ± 2.6	10.5 ± 1.5
F. 'Weekend'	20.0 ± 2.3	21.7 ± 1.1	21.0 ± 3.5

Time of flowering (anthesis) in *Forsythia* 'Lynwood Gold' was not affected by RDI but the shortening of internodes in RDI-treated plants increased the density of flowers per unit length of stem. Therefore, RDI-treated plants appeared more floriferous. Anthesis was not affected by either RDI regime in *Forsythia* 'Weekend' (data not shown).

Effects of RDI on overall plant 'quality' and shelf-life potential

The effects of RDI on overall plant quality at simulated market date are being determined in both *Forsythia* cultivars at the time of writing (March 2008), using the quality criteria developed under Objective 1. *Cornus* plants will be transferred to the Plant Shelf-life Centre (PSLC) where they will be exposed to conditions similar to those measured during retailing in Objective 2. These tests will help determine whether RDI can be used to improve the tolerance of *Cornus alba* species to moderate soil drying and help reduce the loss of quality during retailing.

Experiment 2

Imposition of RDI

The deficit irrigation treatments were imposed on 2 May 2007. Since *Mahonia* plants were grown under cover, plant-and-pot weights of RDI-treated plants began to diverge from WW values within two days and large treatment differences developed during the experiment (Figure 15A). Irrigation was scheduled very effectively and the well-watered plant-and-pot weights were maintained throughout the season. As expected, patterns of SMC mirrored those of plant-and-pot weights. Substrate moisture content of both the 75% and 50% RDI-treated plants were maintained at lower values throughout the 5-month experiment (Figure 15B) until plants were re-wetted during November. Similar trends in plant-and-pot weights and SMC's were noted for *Photinia* which was also grown under cover (data not shown).

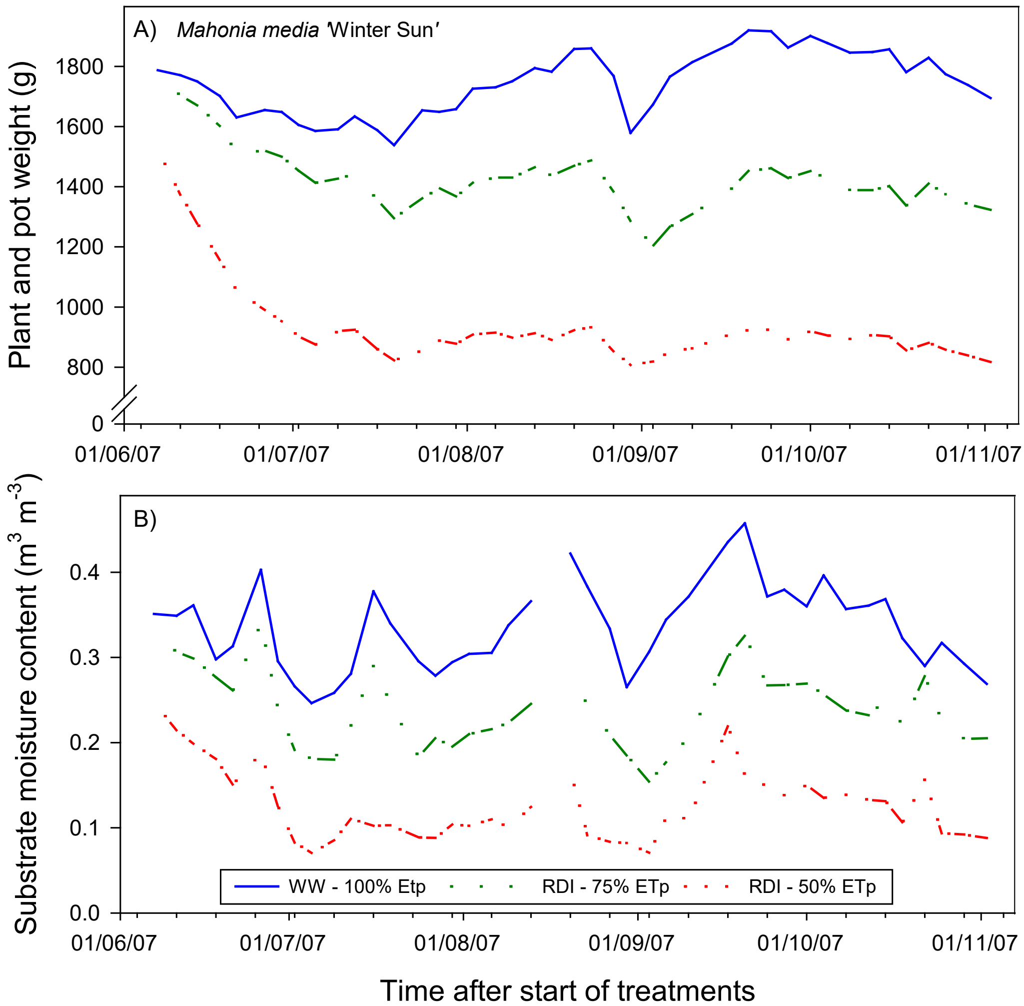


Figure 15. The effects of two RDI regimes imposed on *Mahonia* × *media* 'Winter Sun' during June to November 2007 on A) plant-and-pot weights and B) substrate moisture content. Results are means of six replicate plants.

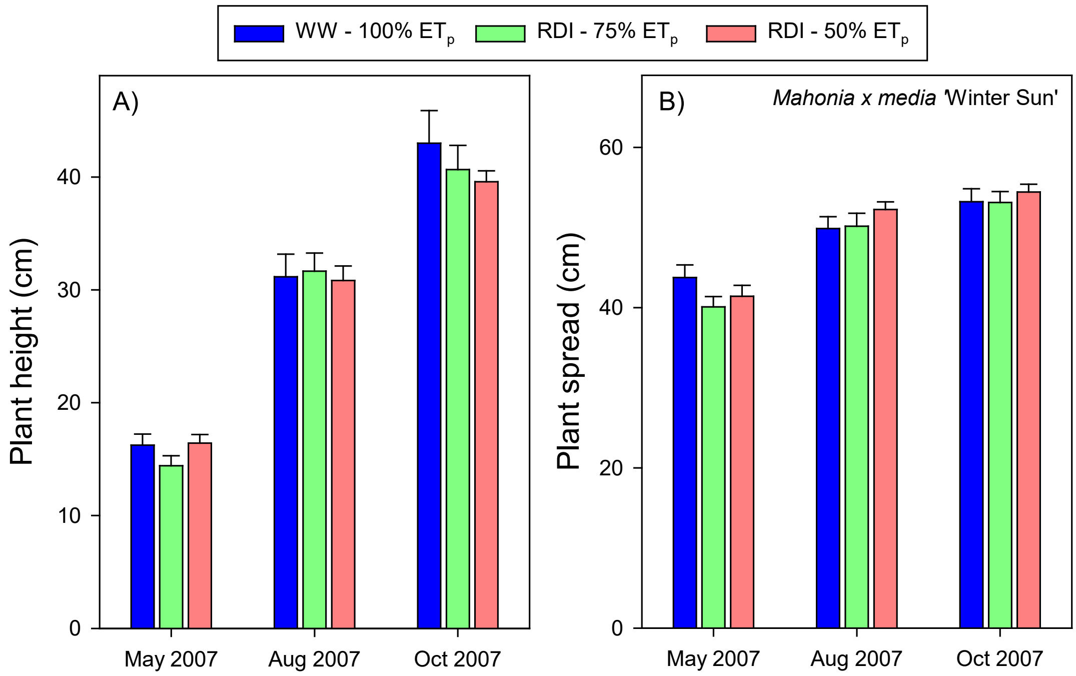
Whole-plant transpiration rates of *Mahonia* were reduced slightly by the RDI-75% regime but were halved by the RDI-50% regime, compared to well-watered values (Table 3). Both RDI treatments effectively reduced *E* in *Photinia* (Table 3).

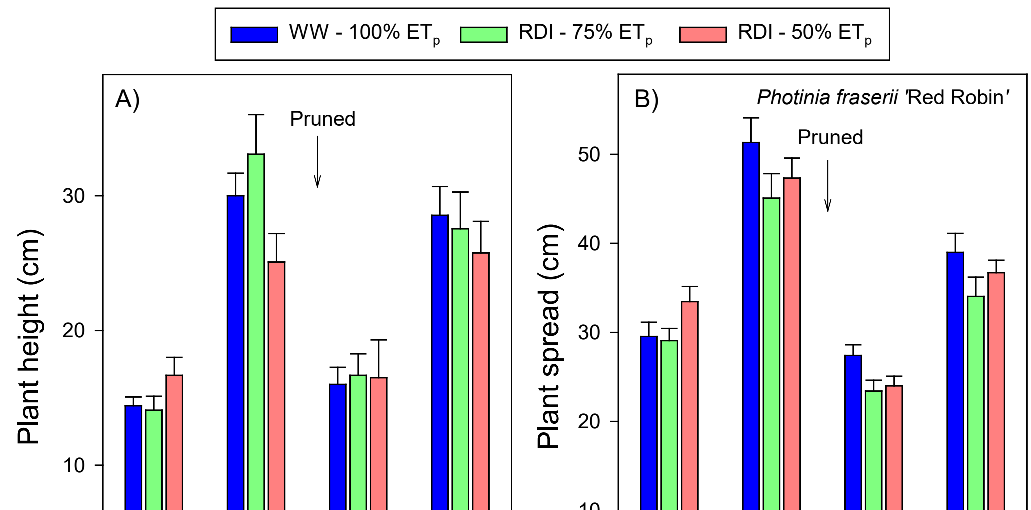
Table 3. Effect of RDI on whole-plant transpiration rates in *Mahonia* × *media* ‘Winter Sun’ and *Photinia fraserii* ‘Red Robin’ measured between 10:00 and 13:00 on 19 July 2007. Results are means of six replicate plants with associated standard errors.

Species	Whole-plant transpiration rate (g h^{-1}) Irrigation regime (% of ET_p)		
	100%	75%	50%
Mahonia	10.5 ± 0.9	9.5 ± 0.5	5.3 ± 0.4
Photinia	10.3 ± 0.7	8.4 ± 0.5	6.2 ± 0.6

Effects of RDI on plant height and spread

Measurements of *Mahonia* plant heights taken at simulated market date (October 2007) indicated a small reduction in RDI-treated plants (Figure 16A); spreads were not affected (Figure 16B). Height was significantly reduced in the 50% RDI-treated *Photinia* plants before all plants were pruned in September to encourage the production of new shoots (Figure 17A). However, this effect was not apparent when plant heights were measured at simulated market date (March 2008). Plant spread was reduced by pruning but was not affected by RDI (Figure 17B).





Effects of RDI on components of plant quality

The RDI-50% treatment delayed the production of racemes (flower stalks) but the total number of racemes per plant was not affected by either RDI treatment (Figure 18A). Anthesis was delayed by one week and by three weeks in the 75% and 50% RDI treatments, respectively (Figure 18B). The most visible effect of RDI was to increase the

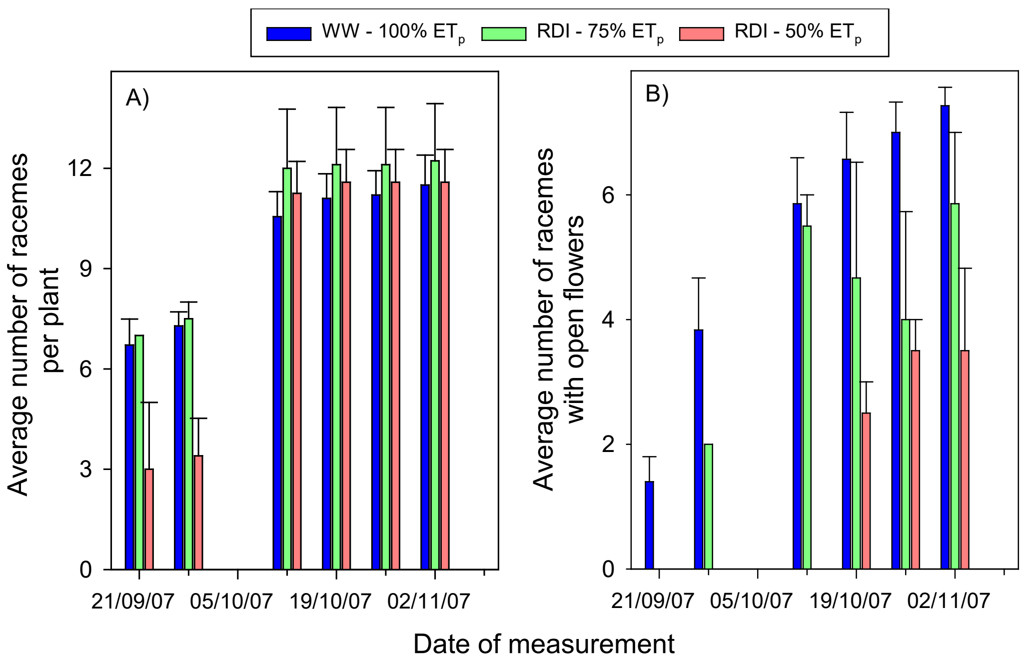


Figure 18. Effects of RDI on A) number of racemes (flower stalks) and B) time of flowering in *Mahonia* × *media* 'Winter Sun'. Results are means of 12 replicate plants, with associated standard error bars.

proportion of red-tinged leaves (Figure 19A); this was particularly prevalent in plants under the RDI-50% regime (Figure 19B). This transition from dark, green glossy leaves to dull, apparently senescing foliage greatly reduced the overall quality of the 50% RDI-treated plants at simulated market date.

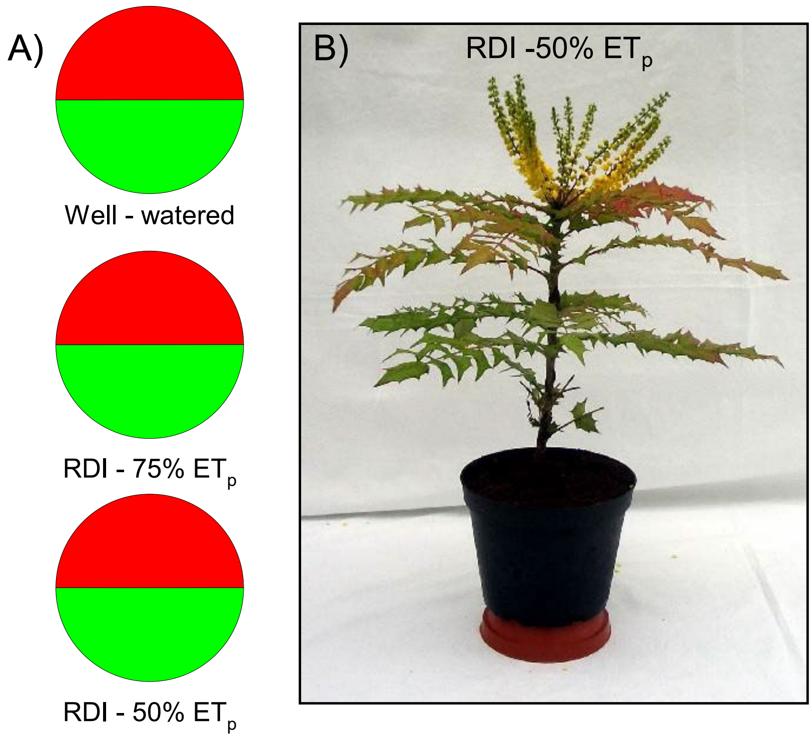


Figure 19. A) Effect of RDI regimes on the proportion of red-tinged leaves on *Mahonia* at simulated market date (October 2007). B) An example of an RDI-50%-treated plant with red-tinged, upper leaves.

In *Photinia*, the number of new shoots formed during the month after pruning was reduced by 18% and 36% in plants receiving 75% and 50% RDI regimes, respectively (Table 4). Although new shoots continued to develop over the winter, there were stil fewer new shoots on the RDI-treated plants at simulated market date (Table 4).

Table 4. Effect of RDI on the number of new shoots in *Photinia* after pruning in September 2007. Results are means of 12 replicate plants with associated standard errors.

Date of measurement	Number of new breaks Irrigation regime (% of ET$_p$)		
	100%	75%	50%
October 2007	12.2 ± 0.9	10.0 ± 0.7	7.8 ± 0.9
December 2007	14.1 ± 1.0	10.9 ± 1.4	11.1 ± 0.6
March 2008	14.3 ± 0.9	10.7 ± 0.9	11.7 ± 0.7

Effects of RDI on overall plant 'quality' and shelf-life potential

Although RDI reduced plant height to within specification (40 cm) at simulated market date, the overall quality of RDI-treated *Mahonia* was reduced due to the effects of the treatments on the foliage. Since the visual appeal of *Photinia* at market date is mostly governed by the bright red new shoots formed over the winter, a treatment such as RDI that limits shoot numbers would reduce overall plant quality.

Experiment 3

Imposition of RDI

RDI treatments were initiated on 8 May 2007, to coincide with the beginning of the first growth flush in the four *Rosa* cultivars. However, heavy rain during the first weeks of May re-wetted the compost in the RDI-treated *Rosa* 'Just Joey' so treatment differences did not begin to develop until the end of May (Figure 20A). Rain during June again reduced the effectiveness of the RDI regimes; the SMC in all treatments was similar at this time (Figure 20B). Some soil drying was achieved during July and by August large

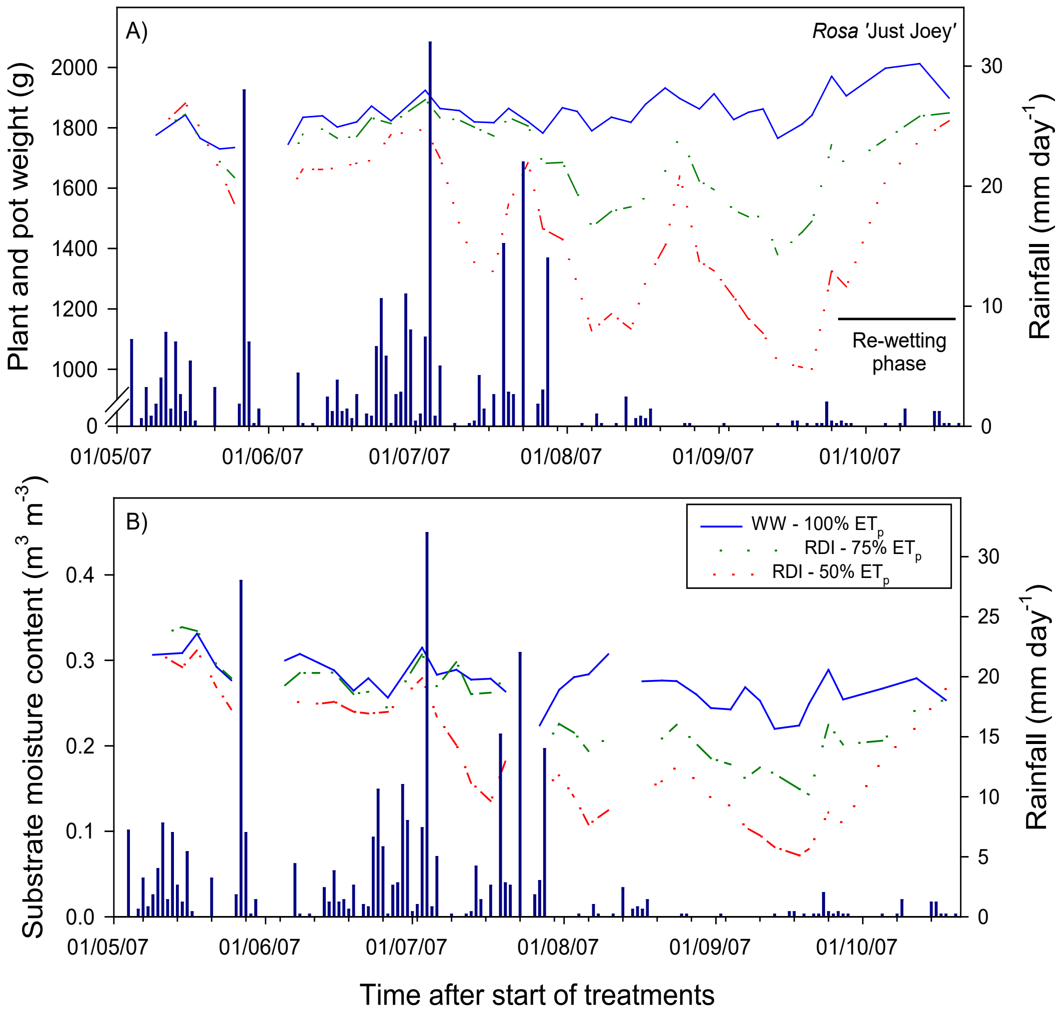


Figure 20. The effects of two RDI regimes imposed on *Rosa* 'Just Joeyl' during May to October 2007 on A) plant-and-pot weights and B) substrate moisture content. Daily rainfall throughout this period is also presented. Results are means of 12 replicate plants.

‘Margaret Merril’ over the experiment were similar to those described above for ‘Just Joey’. All RDI-treated plants were re-wetted during October at the end of the experiment.

Effects of RDI on stem internode length, basal breaking and overall plant quality

The average internode length of cultivars ‘Remember Me’ and ‘Just Joey’ were significantly reduced by both RDI regimes, and by the 75% RDI regime, respectively (Table 5). There were no statistically significant effects of RDI on internode length in the other cultivars (Table 5).

Table 5. Effects of RDI on stem internode length in four *Rosa* cultivars. Results are means of six replicate plants with associated standard errors.

Rosa cultivar	Stem internode length (mm) Irrigation regime (% of ET_p)		
	100%	75%	50%
‘Remember Me’	20.6 ± 1.8	17.8 ± 1.0	15.6 ± 1.0
‘Just Joey’	31.6 ± 2.3	25.0 ± 2.6	28.6 ± 3.5
‘Arthur Bell’	21.8 ± 1.0	21.0 ± 1.5	20.3 ± 1.6
‘Margaret Merril’	23.5 ± 3.0	23.3 ± 1.2	21.7 ± 1.4

The number of breaks per plant was not affected in RDI-treated ‘Margaret Merril’’ and ‘Just Joey’ but was reduced in ‘Arthur Bell’ and ‘Remember Me’ (Table 6). The 50% RDI regime increased the average diameter of the basal breaks in ‘Margaret Merril’, which improved the grade-out of this ‘shy-breaking’ cultivar.

Table 6. Effect of RDI on the number and average diameter of basal breaks in four *Rosa* cultivars. Results are means of nine replicate plants with associated standard errors.

Rosa cultivar	Number of basal breaks Irrigation regime (% of ET_p)			Average diameter of basal breaks (mm) Irrigation regime (% of ET_p)		
	100%	75%	50%	100%	75%	50%
‘Remember Me’	5.3 ± 0.5	5.1 ± 0.4	4.7 ± 0.4	5.8 ± 0.2	5.6 ± 0.2	5.4 ± 0.1
‘Just Joey’	5.0 ± 0.5	4.3 ± 0.4	5.0 ± 0.3	5.7 ± 0.2	5.7 ± 0.3	5.4 ± 0.2
‘Arthur Bell’	6.8 ± 0.4	6.3 ± 0.5	5.3 ± 0.6	5.2 ± 0.2	5.5 ± 0.2	5.5 ± 0.2
‘Margaret Merril’	3.5 ± 0.3	3.3 ± 0.4	3.4 ± 0.4	6.5 ± 0.3	6.9 ± 0.3	7.1 ± 0.2

Effects of RDI on shelf-life potential

The effects of RDI on plant quality will be determined during May-June 2008, when all experimental plants from Experiment 3 will be dispatched in a ‘curtained’ container lorry from EMR and eventually transported to Chessum Plants Ltd at the end of a typical delivery run. The conditions during transit will be logged and the ambient concentration of ethylene inside the container lorry will be measured. Plants will then be transported back to EMR where they will be maintained on the PSLC and subjected to the optimum and minimum soil moisture contents identified at the retail sites during 2007. Overall plant quality will be scored at the end of the six-week test and any effects of pre-treatment with RDI on shelf-life potential will be determined.

Objective 4

Our preliminary measurements suggest that basal ethylene production rates were higher in *Rosa* 'Arthur Bell' than in 'Margaret Merril' and that wound ethylene production increased four-fold within 6 h of excision (data not shown). The minimum ambient ethylene concentration needed to trigger autocatalytic ethylene production in the four different *Rosa* cultivars is currently being determined. The minimum ethylene concentration needed to trigger leaf abscission in the each cultivar will also be identified in dose-response tests. Measurements of ambient ethylene concentrations during distribution and retailing will help to determine whether accumulations of ethylene reduce plant quality at point-of-sale. If so, the feasibility of using ethylene inhibitors (*e.g.* 1-MCP) to reduce ethylene perception and improve shelf-life potential will be determined.

Discussion

Quality criteria

The key quality attribute of roses at point-of-sale is the number and width of the basal breaks; this is a visible and easily quantifiable trait which presumably explains the similarity between the 'expert' and 'consumer' scores. However, there were marked differences in opinion between 'consumers' about whether the graft union should be below or above the compost and confusion over the impact on plant quality. The inconsistency with which some 'consumers' scored quality on consecutive days presumably stemmed from some uncertainty regarding the relative importance of the attributes that determine overall quality. Campaigns to help increase consumer awareness about the most important aspects of plant quality in dormant-stage roses may help to reverse the recent trend of falling sales in this sector.

Conditions during distribution and retailing

The conditions encountered during distribution differed depending on the type of container lorry used. The high RH and fairly constant temperatures encountered during transport in the 'box' and the 'refrigerated' container lorries provide ideal conditions for spore germination in many pathogens including downy mildew, rust and *Botrytis* spp. In contrast, the air movement in the 'curtained' container lorry meant that RH values fell during the day as air temperatures increased. Although these conditions are less suitable for spore germination, they would favour loss of water through transpiration and could result in the development of soil moisture deficits that may reduce shelf-life potential. However, unfavourable conditions during transport are only likely to affect quality if plants are transported over several days. Although growers strive to ensure that plants are free from disease when they leave the nursery, more research is needed to determine whether conditions during protracted transport affect the development of diseases during the subsequent retail phase.

Conditions during the retailing phase varied widely at the different sites. Although irrigation was applied by overhead sprinklers at all sites, plant quality at sites that scheduled irrigation effectively was generally much better than that at sites where irrigation was applied on a rather more *ad hoc* basis. At some sites, the application of overhead irrigation during the evening meant that leaves were wet during the night. Combined with the close spacing and limited air flow through the retailing area, this practice would have exacerbated disease problems. Alternatives to overhead irrigation that would reduce disease pressure, maintain quality and reduce wastage include capillary matting and flood-and-drain systems but more research is needed to determine the feasibility of using these approaches in a retail centre.

Effects of RDI on plant growth and quality

The effectiveness of the RDI treatments on the outdoor crops was reduced in 2007 compared to experiments carried in 2006 (HNS 141 First Year Report), despite the fact that RDI regimes were optimised for each species independently. For example, *Forsythia* 'Lynwood Gold' responded well to RDI in both years and heights were reduced to a similar extent by the 50% regime. However, stem extension growth in *Forsythia* 'Weekend' was limited very effectively in 2006 by both RDI regimes but not in 2007. Transpiration rates were reduced in both *Forsythia* cultivars and in *Cornus alba* so although the plants responded to the mild soil moisture deficits, heavy rain throughout the 2007 growing season undoubtedly reduced the effectiveness of the RDI treatments. Soil moisture contents of '*Forsythia* 'Weekend' were maintained between 0.2 and 0.3 m^3 m^{-3} in 2007 whereas SMC values were frequently reduced below 0.2 m^3 m^{-3} in 2006.

The heavy and frequent rainfall throughout May, June and July also prevented RDI from being imposed effectively in the *Rosa* cultivars during the first and second growth flushes and so any treatment effects on the production of basal breaks were minimised. The average diameter of the breaks was generally lower than that of Class 1 containerised dormant-stage roses but this was presumably a consequence of the maiden bushes being lifted from the field in early March with the inevitable loss of fine roots. These plants were then containerised and were establishing during the first and second growth flush which must have reduced overall vigour compared to those plants left in the field to develop over the summer. Nevertheless, the data suggest that the grade-out of Class 1 bushes could be improved by RDI in some ‘shy-breaking’ cultivars. Even though roses are not grown under cover in the UK, it may be informative to test RDI on covered roses to determine how effective RDI can be under dry conditions. This work would help to determine the feasibility of applying RDI during the production of roses overseas in drier climates where irrigation of the crop is essential.

Our experiments in 2007 suggest that some species do not respond well to RDI. Both *Mahonia* and *Photinia* were grown under cover as is done commercially to optimise the quality of the foliage at point-of-sale. RDI was imposed very effectively under these conditions and both *Mahonia* and *Photinia* responded by closing stomata and limiting transpirational water loss. However, the reductions in quality at point-of-sale would far outweigh any water savings achieved by RDI in these species.

Despite scheduling three separate irrigation events each day, our work with *Cornus* in 2007 highlighted the difficulties in keeping the compost sufficiently moist in the well-watered controls to prevent marginal leaf scorching. In 2008, we propose to use soil moisture probes to trigger irrigation automatically so that the SMC of the well-watered controls can be maintained within narrow limits. This approach has been used very successfully in our current Defra-funded work on poinsettia (HH3609TX) and also in Horticulture LINK 97b on several grower sites.

Shelf-life potential

The susceptibility of *Cornus* to soil drying resulting from inefficient irrigation and the subsequent deterioration in quality was a problem at some retail centres even during the very wet 2007 season. Treatments such as RDI that are able to increase the tolerance to moderate soil drying have great potential to improve equality and reduce wastage during retailing. Whether previous exposure to RDI improves shelf-life potential in *Cornus* will be determined in 2008.

Anecdotal evidence suggests that accumulations of ethylene can promote leaf drop in some rose cultivars and reduce shelf-life potential (Neal Wright - personal communication). Work in 2008 will identify the minimum concentrations needed to trigger leaf abscission during the half-growth stage and our measurements of the conditions encountered during transit will determine whether this minimum concentration is likely to be encountered during distribution. If significant accumulations of ethylene are detected that impact on shelf-life potential, we will test the feasibility of using foliar sprays of ethylene inhibitors (*e.g.* 1-MCP) to improve plant quality at point-of-sale and during retailing. We will also determine whether previous exposure to RDI limits plant sensitivity to ethylene or impairs ethylene biosynthesis.

Conclusions

- Scheduling of irrigation and the imposition of RDI regimes were optimised for each species or cultivar during 2007
- RDI can be delivered to some outdoor crops effectively even in seasons with heavy rainfall
- In other species, the effects of deficit irrigation on overall plant quality can be nullified in such conditions. Nevertheless, water savings of up to 50% can still be achieved
- The degree and duration of soil drying needed to restrict stem extension varies between species and cultivars
- RDI can improve overall quality in *Forsythia*, *Cornus* and some rose cultivars
- Using RDI can increase the thickness of basal breaks and improve the percentage grade-out in some 'shy breaking' rose cultivars such as 'Margaret Merril'
- RDI should not be used on *Mahonia* and *Photinia* since plant quality will be reduced
- Avoiding prolonged periods of high RH during transport may help to reduce disease pressure on roses during subsequent retailing at the half- and full-growth stages.
- Frequent and heavy rainfall combined with inefficient irrigation scheduling resulted in over-wet conditions at several retail sites during June and July 2007. Plant quality at these sites gradually deteriorated over the measurement period
- *Cornus* is particularly prone to leaf desiccation caused by inadequate or inefficient irrigation; this problem is exacerbated if freely-draining compost is used
- There is scope to prevent the deterioration in plant quality and reduce the associated volume of wastage during retailing by improving the precision and scheduling of irrigation

Technology Transfer

1) The project aims, objectives and results to date were presented to members of the Kent Horticultural Discussion during a visit to EMR (July 2007).
2) Our on-going work in HNS 141 was presented to members of the British Rose Growers Association at an HDC/HTA Rose R&D Forum (November 2007).
3) An overview of the project was presented to members of the HTA during a visit to EMR on 18 December 2007.
4) The background and the aims of the project were discussed with sixth-form students during a Science, Engineering and Technology Week event held at EMR (March 2008).
5) Several meetings and discussions were held with Mr David White and Mr Clive Faulder (Chessum Plants Ltd).
6) An article for HDC news describing the background to the project and the results to date is being prepared for HDC News and will be submitted in May 2008.

Glossary

EvapoSensor – an instrument developed at HRI East Malling and now available from Skye Instruments that provides an electrical signal approximately proportional to potential transpiration from a model leaf. It integrates the effects of humidity, radiation, temperature, wind, and leaf wetting.

ET_p – potential evapotranspiration – the rate at which a crop would lose water under prevailing environmental conditions if water supply was non-limiting. It includes evaporation from the plants *i.e.* transpiration and from the growing medium in the container.

Volumetric substrate moisture content – water content of the soil or growing medium expressed as a fraction or percentage of the total volume occupied by water. Its optimum value depends on the type of substrate but is generally between 30 and 40%.

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