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Project number:	HNS 141
Project leader:	Dr Mark A Else, East Malling Research
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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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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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Contents

Headline

The use of Regulated Deficit Irrigation (RDI) has a species-specific impact on plant quality, with some species responding positively and others responding negatively.

Background and expected deliverables

- Industry consultation with growers revealed that the use of controlled release fertilisers had been optimised and that fertigation (the addition of fertiliser via irrigation) was inappropriate for the industry. Therefore, investigation into fertigation management techniques was excluded from the study,

The aim of this project was to determine whether plant quality and shelf-life potential of HNS species and containerised roses could be improved using irrigation management techniques during the production cycle. The HNS sector is a major user of water but 75% of all HNS grower sites are situated within regions where competition for limited water supplies is increasing. Figures show that 40% of HNS growers are in areas classified by the Environment Agency as being either 'over abstracted' or 'over licensed'. Legislation designed to safeguard these resources and limit damage to the environment will place restrictions on future water use and growers will have to demonstrate efficient use of available water before time-limited abstraction licences are renewed. New production methods that improve water use efficiency and also utilise environmental 'best practice' are needed to help HNS growers to comply with legislation while continuing to produce high quality crops.

Irrigation management techniques offer the potential to deliver large water savings while maintaining or improving crop quality. For example, deficit irrigation techniques such as 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. In this project, six HNS species and four rose cultivars were used to determine the effects of deficit irrigation on plant quality and shelf-life potential.

There were 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 included:

- 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 risk of environmental pollution
- Improved crop consistency and uniformity with associated reductions in labour costs

Summary of the project and main conclusions

Quality criteria

The criteria for assessing plant quality in the HNS species and rose cultivars used in the project were developed through consultation with Mr David White (Paul Chessum Roses), Mr David Hooker (Hillier Nurseries) and Mr Danny Elliott (HNS Business Consultant). Quality criteria have been developed for roses at the dormant and half-growth stages and for six HNS species at the point of sale. A scoring system was designed and scores allotted by industry 'experts' (Figures GS1 and GS2).

Score = 5

5-10cm height

5-15cm width

Good pot coverage

Minimum of 3 strong basal breaks

Score = 1

Comments: Weak shoots or 'Dieback' will reduce quality.

Figure GS 1. Criteria used to assess the quality of *Rosa* 'Dutch Gold' at market date. A representative plant of excellent quality (score = 5) illustrates the key criteria; an example of a poor quality plant (score = 1) is presented for comparison.

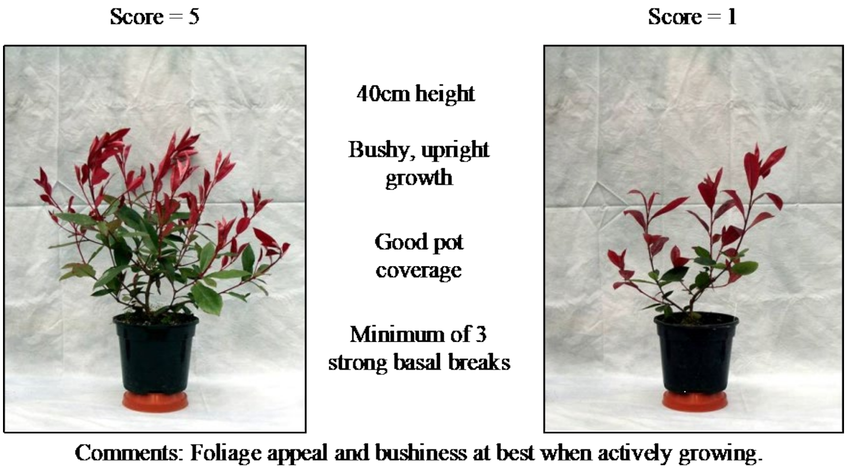

Figure GS 2. Criteria used to assess the quality of *Photinia fraserii* 'Red Robin' at market date

Perception of quality: 'Expert' versus 'Consumer'

Expert' scores were compared to scores given by a 'consumer' group panel consisting of twenty individuals (horticulturists and non-horticulturists at EMR). The agreement between 'expert' and 'consumer' was generally very good for *Forsythia*, indicating that consumers sought the same quality attributes as the expert. The key quality attribute in *Forsythia* at point-of-sale is the number and quality of the flowers; this is a very visible and easily quantifiable trait which presumably explains the close similarity between the 'expert' and 'consumer' scores. There was only fair agreement between the 'experts' and the 'consumers' for *Mahonia*, *Photinia*, and *Cotinus*.

The agreement between 'expert' and 'consumer' was generally moderate to strong for most rose cultivars 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.

Effects of RDI regimes on plant quality

Irrigation to six HNS species and four rose cultivars was scheduled using an EvapoSensor and an EvapoMeter. Well-watered plants received 100% of the daily potential evapotranspiration (ETp). 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 often reduced the effectiveness of the treatments, sufficient soil drying was imposed to influence plant growth and quality in most of the species tested. 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'**:

- Branching potential was improved by RDI
- Plant height and spread were unaffected by RDI
- Leaf reddening and marginal scorch will occur during the first year of production, under extreme RDI regimes

RDI improved the quality of ***Rosa*** **'Just Joey' and 'Remember Me'**

- Internode length (and therefore stem height) was reduced in RDI-treated 'Just Joey' and 'Remember Me'
- The average number of breaks per plant was not affected in RDI-treated ''Just Joey' and 'Remember Me but was reduced in 'Arthur Bell' and 'Margaret Merril'
- Effects of RDI on the diameter of basal breaks were not consistent

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

- Plant height and spread was reduced only slightly by RDI
- RDI did not consistently alter branching potential

RDI did not affect quality of ***Cotinus coggygria*** **'Royal Purple':**

- Plant height and spread were not affected by RDI

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 GS 3)

- 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

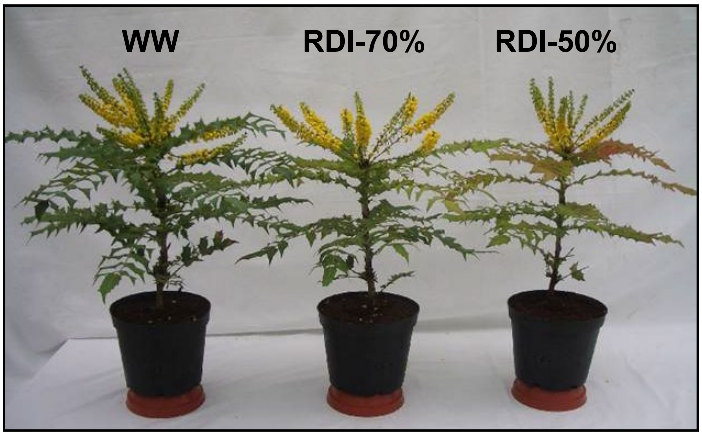

Figure GS 3. RDI 50% reduced *Mahonia* plant height but promoted leaf reddening

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

- RDI regimes reduced plant height before all plants were pruned in September
- 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 shelf-life tests carried out at EMR in 2008 and 2009 failed to demonstrate any positive effects of imposing RDI treatments in the first year of production on the maintenance of quality during a simulated retailing period in the following year. However using RDI to pre-condition mature *Cornus alba* plants (applied during June and July 2009) immediately prior to a shelf-life test (assessed August 2009) slowed the rate of substrate drying when a 'dry' regime was imposed, compared to plants that were previously well-watered. Such an RDI treatment could help maintain a more favourable substrate moisture content in the retail environment and could slow the rate of deterioration in quality. The rapid substrate drying was presumably a consequence of high rates of transpirational water loss in plants that were previously well-watered when they were first exposed to a 'dry' regime.

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 of roses 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 ^{o}C in the ‘curtained’ container lorry while temperature was maintained between 13 ^{o}C and 20 ^{o}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 ^{o}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 impact of transportation choice on plant quality would be dependant upon the length of time plants spend in transit.

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, substrate moisture content (SMC), E.C. levels, leaf chlorophyll content (a proxy measure of leaf nitrogen status) and transpiration rate were determined on each occasion. SMC was chosen as the most reliable criterion for assessing the degree of stress encountered during retailing.

- 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 were imposed during shelf-life tests at EMR in 2008 and 2009.

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 T	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 substrate 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 GS 4).

Figure GS 4. 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 at retail outlets.

Effect of ethylene on rose quality

The effects of the gaseous plant hormone ethylene on leaf abscission and overall plant quality were determined in dose-response tests. Preliminary tests established that exposure of *Rosa* 'Remember Me' to 20 parts per million (ppm) ethylene for 24 h resulted in extensive leaf yellowing and abscission (Figure GS 5A). However, no effects of exposure to 1, 5, or 10 ppm ethylene for 24 h on the extent of leaf yellowing or the rate of leaf abscission were noted in any of the *Rosa* cvs (Figure GS 6). Ten ppm ethylene is a very high concentration and such accumulations of ethylene during transit and retailing would be very unlikely. Although some *Rosa* cvs are very susceptible to this gas, the decline in quality of the cvs used in this work could not be attributed to exposure to ethylene.

Figure GS 5. A) Effect of a 24-h exposure to 20 ppm of ethylene on leaf abscission in *Rosa* 'Remember Me'. B) Control plants were treated similarly but were not exposed to ethylene.

Financial benefits

Imposing RDI will reduce water use, but it will only lead to improvements in plant quality, uniformity and shelf-life potential in some HNS species and rose cultivars. The ease and efficiency with which RDI can be applied also depends on the irrigation systems and the management practices on individual nurseries. Upgrading or replacing existing irrigation systems may be necessary to implement RDI effectively on some nurseries; labour costs associated with hand-watering may then be reduced. Therefore, a full cost-benefit analysis is required to ascertain the financial benefit associated with using RDI to improve water use efficiency, enhance quality at the point-of-sale and improve shelf-life potential. This type of analysis has recently been carried out in HNS 97b.

The inhibitory effect of RDI on stem extension in Hybrid T roses may enable four shelves to be used on each Danish trolley during transport, rather than the three shelves currently used. This could help to reduce transport costs and improve the carbon footprint of the industry.

Figure GS 6 Rosa 'Arthur Bell' seven days after a 24-h exposure to 10 ppm ethylene. No leaf yellowing or abscission was noted in any of the ethylene dose response tests using concentrations of 1, 5 or 10 ppm ethylene.

Action points for grower

Pre-conditioning plants by applying a mild RDI treatment in the weeks before dispatch could help to reduce rates of water loss and substrate drying during retailing, which would help to maintain quality.

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 at retail outlets.

- RDI can improve overall quality in *Forsythia* × *intermedia* 'Lynwood Gold' and *Cornus alba* 'Elegantissima'.
- Water savings of up to 50% can be achieved by using RDI without reducing the quality of *Forsythia* × *intermedia* 'Weekend' and *Cotinus coggygria* 'Royal Purple'.
- 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
- *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
- RDI can reduce stem height by 20% in Hybrid T roses; in addition to producing a more compact plant with greater visual appeal, this may also help to reduce transport costs
- Applying mild RDI in the weeks before dispatch may help to pre-condition plants against episodic and uneven watering during retailing
- RDI can be used to improve the quality of some outdoor crops even in seasons with heavy rainfall
- 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
- Growers should continue to emphasise to retailers the importance of good irrigation scheduling if high plant quality is to be maintained at retail outlets
- 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

Hardy Nursery Stock (HNS) growers are becoming increasingly concerned about the effects that climate change will have on their businesses. A key concern is the future availability of water for irrigation. An estimated 81% of all HNS produced in England and Wales is reliant on irrigation to ensure that quality at market date matches the specifications demanded by retailers and consumers (Knox *et al*., 2009). HNS growers used an estimated 25 million cubic metres of water in 2005 (Weatherhead, 2006); however, this was considered to be one of the wettest in the last 35 years and other estimates place the volume nearer to 50 million m^3 (King *et al*., 2006). Thus, the HNS sector is a major user of water. However, 75% of all HNS grower sites lie within regions where competition for limited water supplies is increasing and 40% are in areas classified by the Environment Agency (EA) as being either 'over abstracted' or 'over licensed' (Figure 1). Abstraction rates in these areas are already unsustainable and are predicted to rise by a further 30% by 2050 (Defra WU0102). Legislation designed to safeguard these resources and limit damage to the environment (e.g. Water Framework Directive 2000, The Water Act 2003) will place restrictions on future water use and growers will have to demonstrate efficient use of available water before time-limited abstraction licences are renewed. Although a few larger HNS growers now capture and recycle water, 94% of smaller nurseries rely on mains supplies (Briercliffe *et al*., 2000) and the diversity of the crops produced means that there is a heavy reliance on overhead irrigation. In container-grown crops, growers often irrigate to maintain substrates at pot capacity but only 20-40% of water applied by overhead systems is retained within the containers (Beeson and Knox 1991) and inefficient systems typically misplace between 50 and 80% of the water applied (ADAS 2008). The use of mains water to irrigate HNS will become increasingly expensive and environmentally undesirable as water companies strive to maintain supplies. New production methods that improve water use efficiency and also utilise environmental 'best practice' (ADAS 2008) are needed to help HNS growers to comply with legislation while continuing to produce high quality crops.

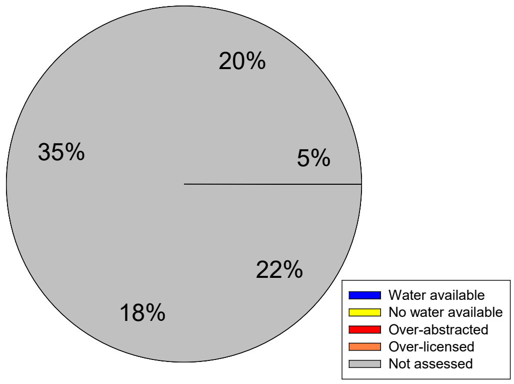

Figure 1. Assessment of water resource availability (for direct abstraction) for the Hardy Nursery Stock sector in 2008 (re-drawn from Knox *et al*., 2009).

These unavoidable issues have recently focussed attention on irrigation techniques that enable more efficient use of water. Several key projects have made good progress towards achieving this goal (*e.g.* HNS 97, HNS 97b, Defra HH3731SHN, HNS 122). Work in HNS 97 identified that uneven water application was a major cause of lack of uniformity and HNS growers increasingly recognise that good management of irrigation will help to reduce labour costs associated with hand-watering, removing liverworts from the substrate surface after over-irrigation and with grading of plants for marketing.

One of the objectives of HNS 97b (HL0168LHN) is to establish whether irrigation scheduling can be implemented successfully in the commercial production of diverse 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 water use efficiency and 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 (Grant *et a*l., 2007). However, the large capital investment and suitable flat land needed for this approach demands that these potential advantages are verified and quantified. The gantry approach has been developed further in HNS 97b and a full cost benefit analysis will be included in the final report of that project (Dr Olga Grant, personal communication).

In addition to effective irrigation scheduling, Regulated Deficit Irrigation (RDI) is an attractive management option, especially in areas where water resources are limited. The potential of RDI to deliver further water savings into the HNS sector is currently being determined in HNS 97b. RDI 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. In addition to restricting water loss from the shoots, some of these chemical signals are also likely to influence plant 'robustness', plant habit, time of flowering and, as a result, visual appeal.

RDI has considerable potential as a means of non-chemical growth control if the application and regulation of irrigation is sufficiently precise (Cameron *et al.*, 2006). Work in a Defra-funded project (HH3609TX) has also shown that RDI can improve 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 several days without watering to simulate conditions in the retail environment. Only when the plants encountered these sorts of stresses do the added benefits of deficit irrigation become apparent. Cameron *et al* (2008) also reported that RDI could improve the tolerance of *Forsythia* to subsequent episodes of drought, possibly *via* an increased capacity for osmotic adjustment which maintained a more favourable leaf water balance and prevented leaf wilting.

The aim of this project was to determine whether RDI could be used to improve HNS plant quality and shelf-life potential. At the outset, it was envisaged that plant nutrition could also be manipulated to modify growth and shelf-life but after several conversations with both HNS and rose growers, it was clear that rates of incorporation of controlled release fertilisers had already been optimised by the industry and tailored towards different production cycles. The addition of fertiliser *via* irrigation (fertigation) was considered inappropriate for HNS production and so the work focussed on quantifying the benefits of irrigation management techniques on plant quality.

Firstly, we determined the effects of RDI on plant quality in several HNS species at simulated market date. The individual components (*e.g.* height, spread, branching framework) that determine overall plant quality 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 RDI on plant quality are to be determined accurately and reproducibly.

Figure 2. Poor quality plants 'reduced to clear' at one of the retail sites in 2007.

Secondly, we determined 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 in the HDC training DVD on Ornamental Plant Care. Increased tolerance to these stresses as a result of treatments such as RDI would help to reduce wastage in-store (Figure 2) and also benefit consumers.

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. The work also delivers into the new HDC Water Strategy where efficient irrigation, improved scheduling and an improved understanding of the link between poor irrigation uniformity and crop profitability (yield and quality) have been identified as key priorities for the HNS sector.

Format of the Final Report

The format will follow HDC guidelines on reporting procedures for Final reports, namely that previously reported work should be included in outline with the final year's work reported in detail. Full details of the experiments carried out in 2006-2007 and in 2007-2008 can be found in the Annual Reports for HNS 141. The work will be reported on the basis of separate Objectives.

Objective 1. To develop criteria for the assessment of plant quality (2006-2007)

Materials and Methods

Criteria were developed for six HNS species and four *Rosa* cultivars. The quality criteria for the *Rosa* cultivars (cvs) were developed by David White and his colleagues at Paul Chessum Roses. 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 (Figure 3). The scoring was then repeated by an EMR 'consumer' panel consisting of twenty individuals (horticulturists and non-horticulturists) as in HDC PC 200. The consistency with which the 'consumers' scored each rose cultivar on consecutive days was also assessed. Scores between the two groups were compared to determine whether the perception of plant quality at point-of-sale differed between 'experts' and 'consumers'.

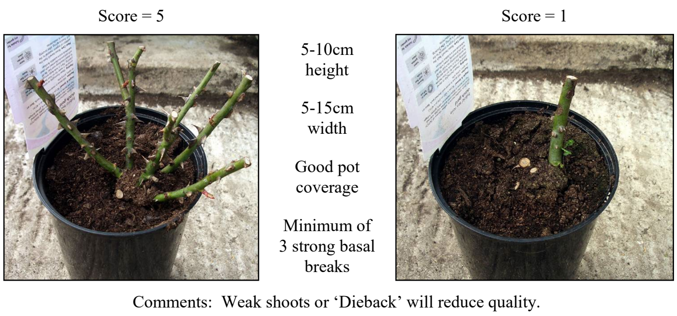

Figure 3. Criteria used to assess the quality of *Rosa* 'Dutch Gold' at market date. A representative plant of excellent quality (score = 5) illustrates the key criteria; an example of a poor quality plant (score = 1) is presented for comparison.

Quality criteria for HNS species were developed after discussions with David Hooker (Hillier Nurseries) and Danny Elliott (HNS business advisor). The key quality attributes for a representative HNS species are presented along with examples of 'excellent' and 'very poor' quality plants (see Results). Scores between 1 and 5 were allotted by an 'expert' and these scores were again correlated with those of the 'consumer' group at EMR.

Results and Discussion

Quality criteria for Rosa cultivars

The most important factor determining the quality of dormant-stage roses is the number of basal breaks; a minimum of three strong basal breaks are required for a Class I rose bush (Figure 3). Therefore, any treatment that can improve basal breaking will increase the grade-out of Class I bushes, currently estimated at only 60%. Retailers also require good pot coverage; the height and width restrictions can be readily achieved through careful pruning. Weak shoots or 'dieback' in pruned shoots will reduce the overall quality.

Quality criteria for HNS species

For many HNS species, one of the most important quality criteria is a minimum of three good, strong branches at the base of the plant, giving rise to a uniform framework of upright branches. In other species such as *Mahonia,* a single stem is often preferred (Figure 4) although multiple stems can increase value. Obviously, quality attributes vary with species and criteria for other species are given in the 2007 Annual Report where examples of plants scoring 5 (excellent quality) and 1 (very poor quality) are also presented, along with more general comments on plant quality.

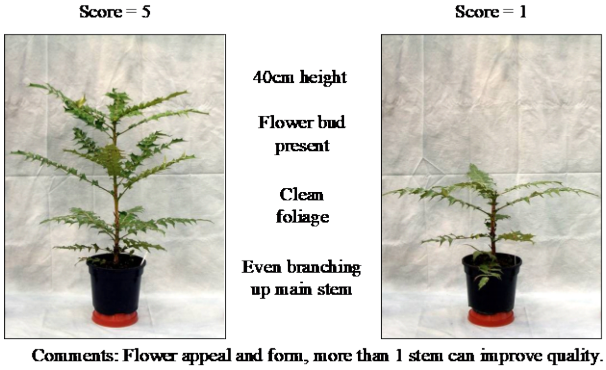

Figure 4. Criteria used to assess the quality of *Mahonia x media* 'Winter Sun'. A representative plant of excellent quality (score = 5) illustrates the key criteria; an example of a poor quality plant (score = 1) is presented for comparison.

Perception of quality: 'Expert' versus 'Consumer'

Correlation analysis was used to compare the 'expert' score to scores given by a 'consumer' group; a correlation value of +1 indicates perfect agreement, 0 equals no agreement, -1 implies complete disagreement between the 'expert' and 'consumer' scores. The correlation between 'expert' and 'consumer' was generally very good for *Forsythia* (Figure 5), the mean correlation value was 0.88 (± 0.04) indicating that consumers sought the same quality attributes as the expert. The key quality attribute in *Forsythia* at point-of-sale is the number and quality of the flowers; this is a very visible and easily quantifiable trait which presumably explains the close similarity between the 'expert' and 'consumer' scores.

The mean value of the correlation between 'consumer' and 'expert' scores for *Mahonia x media* 'Winter Sun' was 0.35 (± 0.13), which indicated only a fair agreement between the two groups. Some 'consumers' scored plants that were the tallest as the best quality, while several preferred the very 'compact' plant that had been pruned at the nursery and was allocated a score of 1 by the 'expert'. The majority preferred an intermediate height, with shorter internodes and even branching up the main stem. Treatments such as

RDI that have the potential to limit stem elongation, thereby producing more compact plants, may help to increase the visual appeal of ***Mahonia*** at point-of-sale.

The 'consumer' group were also asked to score plants on consecutive days. When assessing the quality of 'Abbeyfield Rose', over half of the 'consumers' agreed strongly with the experts on the first day of scoring (Figure 6). 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*** cvs 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.

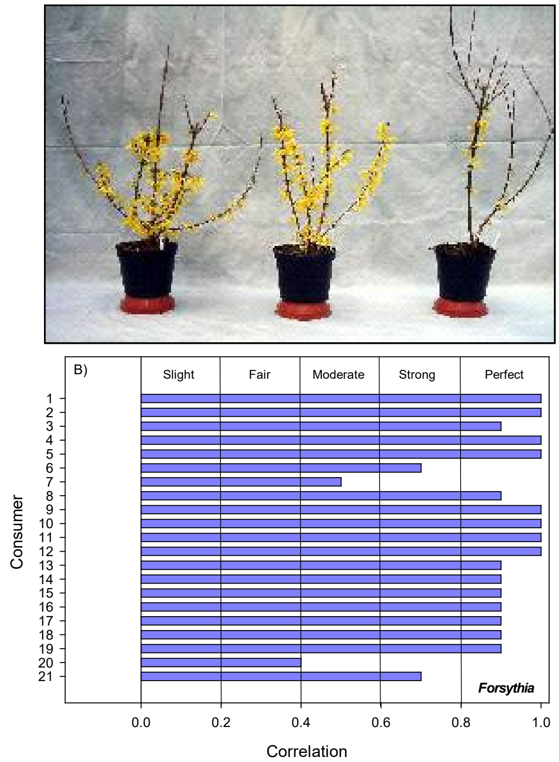

Figure 5. A) Representative plants (***Forsythia x intermedia*** 'Lynwood Gold') of decreasing quality from left to right, as determined by an HNS 'expert'. B) Correlation between 'expert' score and individual 'consumer' scores for plants of quality 1 to 5 (correlation of +1 indicates perfect agreement, 0 = no agreement, -1 = complete disagreement).

Objective 2: To define and duplicate conditions encountered during retail transport and shelf-life (2007-2008)

Materials and Methods

Conditions during transport

Data loggers ('TinyTag Plus 2') were placed inside 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

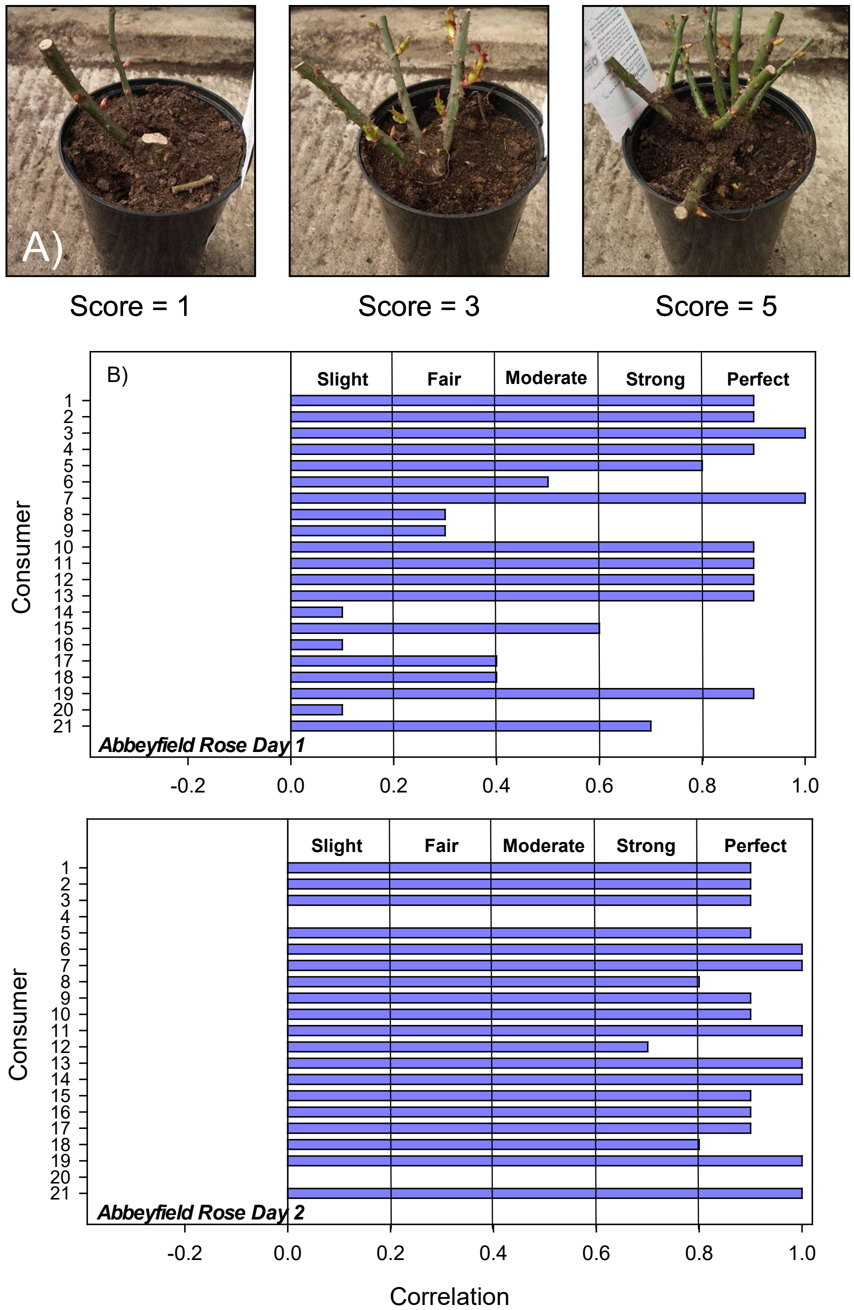

Figure 6. A) Criteria used to assess the quality of ***Rosa*** 'Abbeyfield Rose' at point-of-sale. A representative plant of excellent quality (score = 5) illustrates the key criteria; an example of a marketable plant (Score = 3) and a poor quality plant (score = 1) are presented for comparison. B) Correlation between 'expert' score and individual 'consumer' score for plants of quality 1 to 5 on consecutive days (correlation of +1 indicates perfect agreement, 0 = no agreement, -1 = complete disagreement).

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.

Conditions during retailing

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 Plus 2' data loggers were placed at some sites to track air temperatures and relative humidity during May, June and July.

Results and Discussion

Conditions encountered during distribution

Conditions in three different types of container lorry were compared during the distribution of dormant-stage roses in February 2007. Although conditions varied according to the type of container used (see Annual Report 2008), the shelf-life potential of dormant stage roses is unlikely to be affected by conditions during transport and further measurements were made in 'curtained' and 'refrigerated' container lorries during distribution of roses at the half-growth stage (Figure 7). During the day, air temperatures reached 30 °C and RH fell to 45% inside the 'curtained' container lorry (Figure 7A). 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 7B).

These conditions were duplicated in tests designed to determine whether the quality of two *Rosa* Hybrid T's and two Floribunda's could be reduced during transport by accumulations of the gaseous plant hormone ethylene (see below).

Conditions encountered during retailing

Since pot sizes varied between different retail centres, substrate moisture content (SMC) was chosen as the most reliable criterion for assessing the degree of stress encountered during retailing. The large differences in the degree of substrate drying between sites (see Annual Report 2008) suggested considerable variation in the efficiency and precision of irrigation at the different retail centres. Heavy and prolonged rainfall during June and July made scheduling of irrigation difficult and some species were consistently over-watered at some sites.

Maximum and minimum SMC values for each species were identified from the measurements made at the retail centres in 2007 (Table GS 1). These values were then used in experiments at EMR to determine whether plants previously exposed to RDI during the production cycle had an increased tolerance to the environmental stresses encountered during retailing (see below).

Deterioration in quality during retailing

The effects of the stresses encountered during retailing 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. In contrast, the cumulative effect of ineffective irrigation of *Cornus*

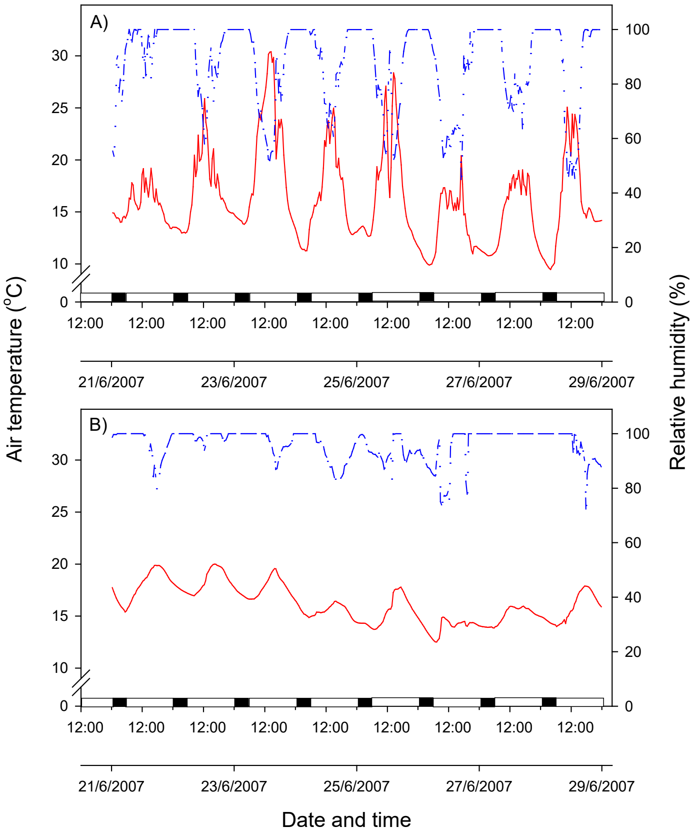

Figure 7. Air temperature and relative humidity inside A) a 'curtained' container lorry and B) a 'refrigerated' container lorry during the distribution of roses at the half-growth stage.

alba resulted in extensive substrate drying (< 0.2 m^3 m^{-3}) at some sites (Figure 8). 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 (Figure 9, Site #5 and Site #7), greatly reducing the marketability of these plants. At Site #6 (Figure 9), pots containing *Cornus* spp. were placed in a wooden lattice to prevent them being blown over and irrigation was generally sufficient to prevent excessive substrate drying. Consequently, these plants remained in good condition throughout the 6-week assessment period.

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 (*e.g.* Figure 10). Plants were frequently standing in water and SMC values were often high (> 0.5 m^3 m^{-3}) indicating over-wet compost. The development of blackspot and downy mildew was particularly severe under these conditions. 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).

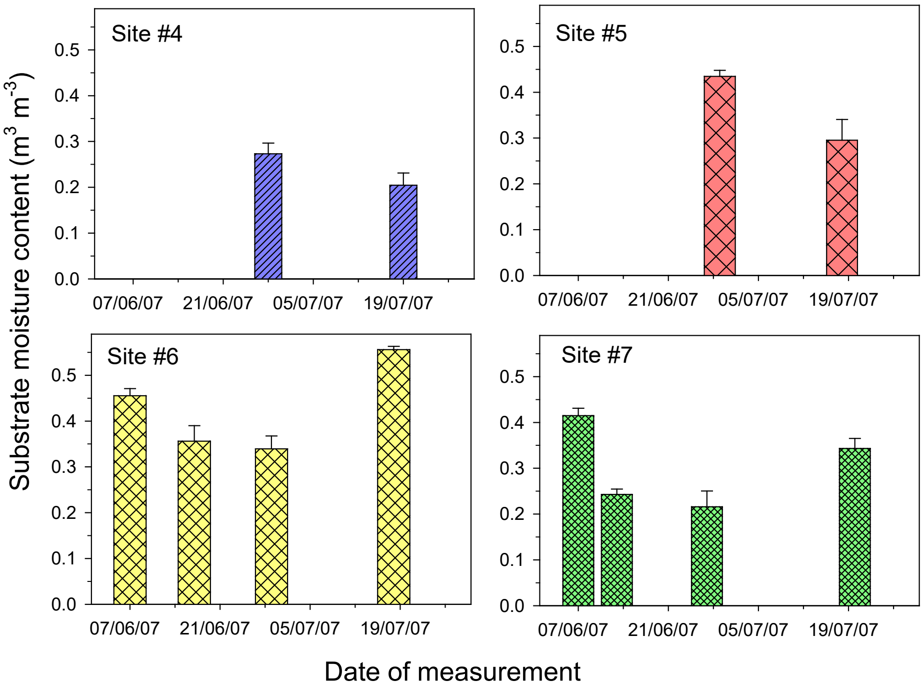

Figure 8. Substrate moisture contents of potted *Cornus alba* plants measured at four retail centres during June and July 2007.

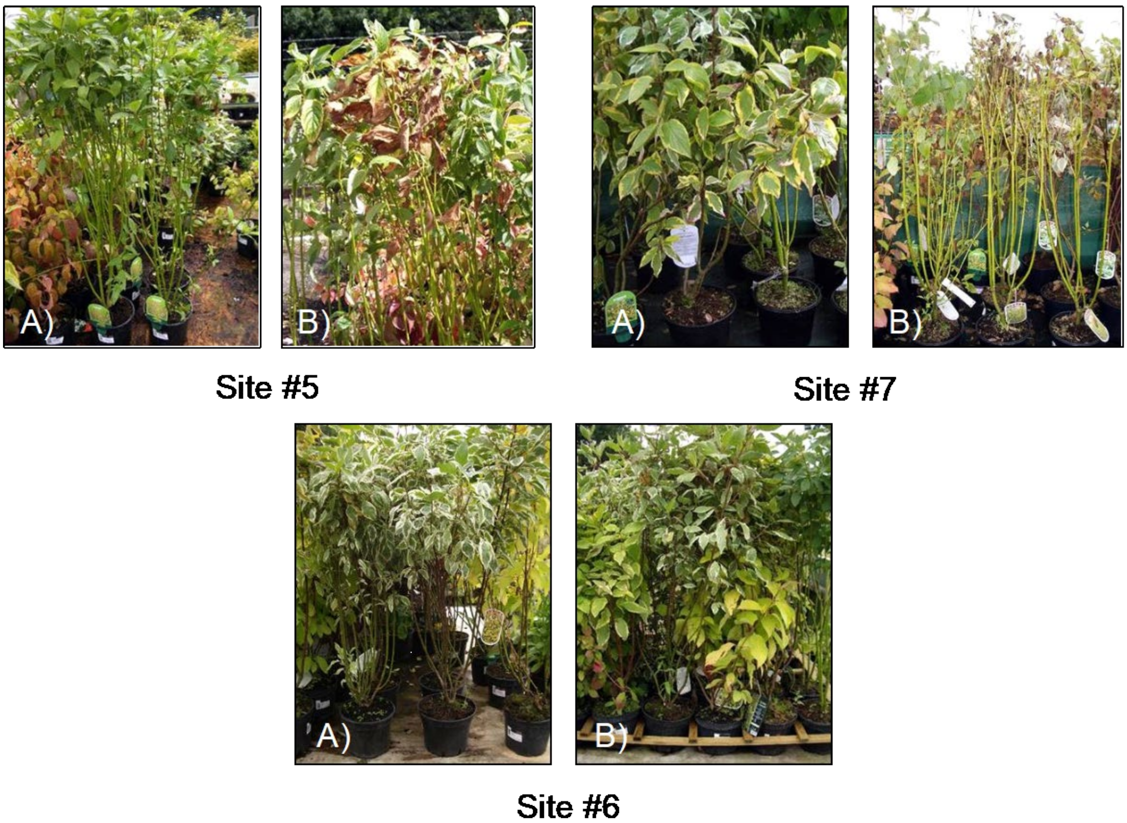

Figure 9. Examples of *Cornus alba* spp. at three different retail centres. At each site, photo A) was taken during the first week of June while photo B) was taken in the third week of July.

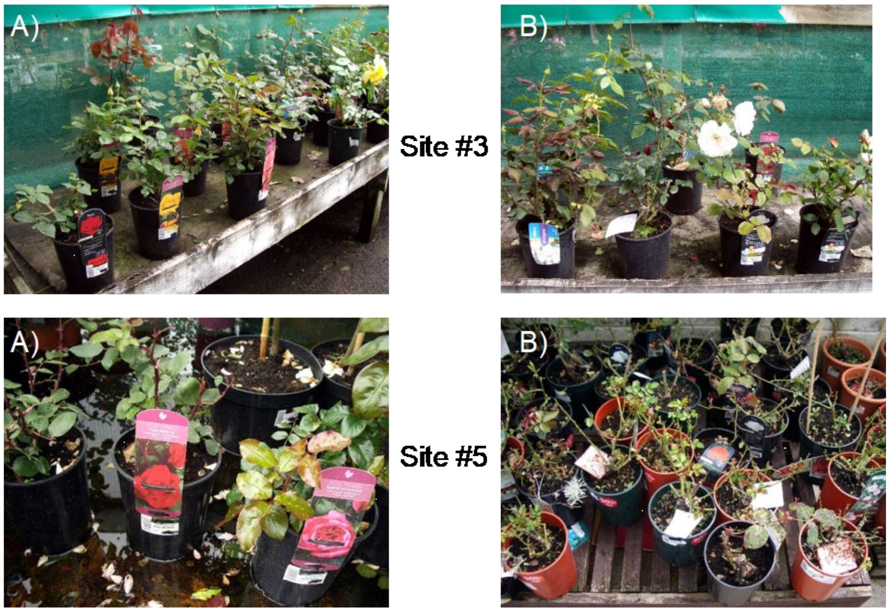

Figure 10. Examples of the deterioration of *Rosa* cultivars during retailing at two retail centres. At each site, photo A) was taken during the first week of June while photo B) was taken in the third week of July. Note standing water in photo A) at site #5.

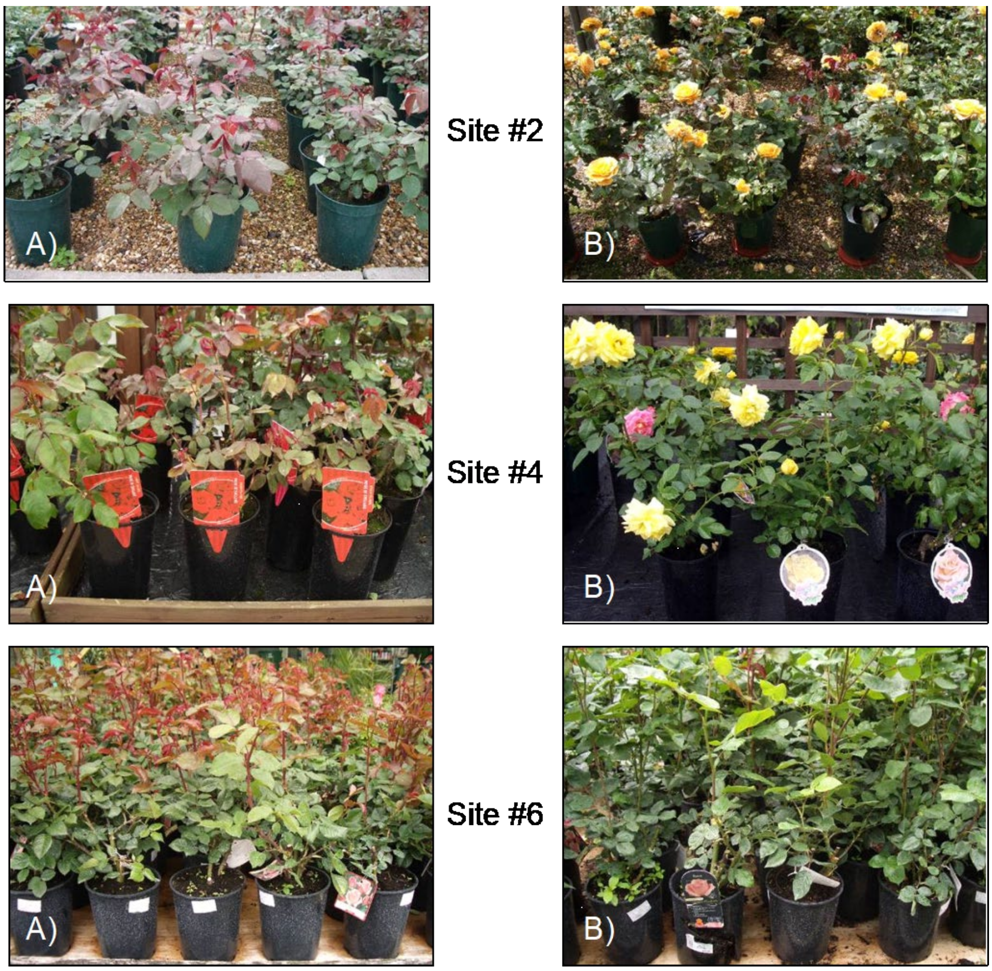

Figure 11. Examples of good quality *Rosa* cultivars available throughout the summer at three different retail centres. At each site, photo A) was taken during the first week of June while photo B) was taken in the third week of July.

Objective 3: To determine the impact of irrigation regimes on quality and shelf-life (2006-2009)

Experiments to determine the potential to use RDI to improve components of plant quality were carried out in 2006 and 2007 on six HNS species and four *Rosa* cvs. The materials and methods and the results generated are reported in detail in the two Annual Reports. In 2008 and 2009, experiments were carried out to determine the potential of using RDI to improve and extend shelf-life potential by bestowing an increased tolerance to stresses encountered during retailing. The most commonly occurring stress identified was that of severe substrate drying resulting from inadequate or inefficient irrigation regimes at some of the retail centres. During visits to the retail sites, it was apparent that the deterioration in quality during retailing was an issue with *Cornus alba* and *Rosa* cvs and so these were chosen for experiments in 2008-2009.

Materials and Methods

Plant material

Maiden bushes of *Rosa* 'Remember Me', *Rosa* 'Just Joey', *Rosa* 'Arthur Bell' and *Rosa* 'Margaret Merril' were sourced from Chessum Plants Ltd. Bare-rooted stocks were potted into 3 L pots containing compost sourced from Chessum Plants Ltd. All pots were maintained on mypex-covered sand beds and hand-watered during a 4-week establishment period. Empot carriers were used to ensure that all plants remained upright throughout the experiments; plants were spaced at 30 cm. Rootstock suckers were removed as and when necessary.

In 2008, liners of *Cornus alba* 'Elegantissima' in 9 cm pots were potted on into 3 L pots containing substrate sourced from New Place Nurseries Ltd. In 2009, *Cornus* plants in 3 L pots were sourced from Hillier Nurseries. In each year, all plants were hand-watered immediately after potting and placed out on mypex-covered sand beds at EMR where they were left to establish for four weeks. Empot carriers were used to ensure that all plants remained upright throughout the experiments; plants were spaced at 30 cm.

Irrigation application and scheduling

Each pot was irrigated using pressure-compensated, non-leakage drippers (Netafim 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. *Cornus* plants and each *Rosa* cv. were irrigated using separate irrigation lines so that volumes could be adjusted precisely to match demand throughout the experiment.

For *Rosa* cvs, irrigation treatments were applied as a percentage of potential evapotranspiration (ETp) as in 2006 and 2007. Irrigation regimes of 100% (well watered), 75% or 50% ETp were applied; ETp 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 (Figure 12). 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 weekly 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

Figure 12. The Evaposensor used to estimate daily evaporative demand for use in irrigation scheduling during the Rosa RDI experiment in 2008.

$$F = \frac{W}{E_{acc}}$$

F was calculated for each HNS species or *Rosa* cultivar separately. Irrigation was applied four times daily (08:00, 12:00, 16:00 and 20:00) to minimise the risk of over-watering or run-through from the pots. Each event replaced the relevant percentage of ETp 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, 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.

In experiments carried out in the first two years of this project, the difficulties associated with maintaining an adequate SMC value in *Cornus* were apparent, even though water in our experiment was applied directly to the substrate *via* drippers and irrigation was pulsed throughout the day to minimise run-through. Therefore, in 2008 and 2009, irrigation was scheduled automatically to ‘well-watered’ *Cornus* plants using a soil moisture sensor (SM200) and a data logger (GP1 – Delta-T Devices, UK) connected to a Galcon Irrigation controller. The irrigation timer was set to ‘cycle’ mode so that a 15-min irrigation event was scheduled every hour. A minimum SMC value needed to maintain high quality in well-watered plants was identified from our previous experiments and used as an SMC threshold value. Once this value was reached, irrigation was triggered automatically for 15 min. When the preset SMC threshold was exceeded, the signal from the Galcon controller was over-ridden by the GP1 so that irrigation was cancelled until the lower threshold was again reached. The thresholds were altered several times throughout the experiment to ensure that SMC was maintained within the optimum range for well-watered *Cornus* (Figure 13).

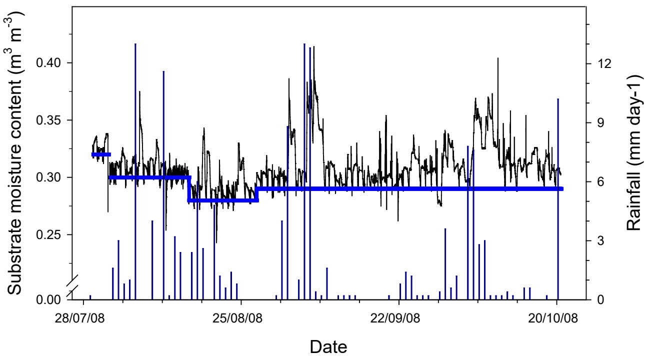

Figure 13. Substrate moisture content in a representative well-watered *Cornus alba* plant (black line) measured continuously with a SM 200 probe connected to a GP1 data logger (Delta T-Devices). The SMC thresholds used to trigger irrigation automatically throughout the experiment (horizontal blue line) were adjusted to ensure that well-watered plants remained well-watered. Daily rainfall throughout the experiment is also shown (vertical blue line).

Two RDI regimes, 75% and 50% of the volume applied to well-watered plants, were also imposed using this system. Although all plants were irrigated from the same irrigation line, water was delivered *via* drippers with outputs of either 2 or 3 L h^{-1}, rather than the 4 L h^{-1} drippers used in the well-watered treatment. Consequently, moderate substrate drying developed and was maintained in the two RDI treatments. A 'late RDI' regime was also imposed to test whether short-term exposure to drying substrate was sufficient to bestow tolerance to stresses encountered during retailing. RDI regimes of either 75% or 50% were imposed from the beginning of September until the end of October 2008 by using estimates of ETp as described above.

Monitoring RDI regimes

In each experiments, plant-and-pot weights were determined twice weekly throughout the experiment using a portable balance (ScoutPro 4000, Ohaus UK Ltd, UK). Whole plant-transpiration was measured gravimetrically (between 09:00 and 13:00) each week. The substrate volumetric moisture content (SMC), E.C. levels and substrate 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 growing media 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 the experimental plants.

Following significant rainfall events during the season, irrigation to the *Rosa* cvs was suspended until the pot weights had returned to the values recorded at the last measurement date. No adjustments were needed with the GP1-automated system as substrate wetting from rainfall events merely delayed the timing of the next irrigation event.

Components of plant quality

Plant heights and spreads, and the numbers of new branches produced were measured at intervals throughout the growing seasons. In the *Rosa* experiment, the numbers of basal breaks were recorded during the first and second growth flushes and again at the end of the dormant season (March 2009). Stem height was measured at the end of the growing season and the lengths of the internodes on one stem were measured below 15 cm stem height and the average internode length per rose bush calculated.

Shelf-life tests

Shelf-life tests were carried out on outside benches at EMR in 2008 and in 2009. The approach was to impose 'wet' or 'dry regimes to achieve SMC values similar to the maximum and minimum values measured at the retail sites (Table GS 1). In 2008, an overhead irrigation system was installed and irrigation events were set for the late evening and early morning to mimic typical irrigation strategies during retailing. To impose the 'dry' regime, the number of irrigation events was the same as for the 'wet' regime but the length of each event was halved.

Cornus, Photinia and four *Rosa* cvs that had previously been exposed to the three irrigation regimes (well-watered, RDI 75% or RDI 50%) during the 2007 growing season were placed on the outside benches in June 2008 (Figure 14). Equal numbers of plants from each irrigation regime were placed in either a 'wet' or 'dry' regime and plant-and-pot weights and SMC were measured regularly throughout the six-week test. At the end of the test, all plants were scored for overall quality using the criteria developed under Objective 1 for *Cornus*, *Photinia* and *Rosa* cvs.

Figure 14. *Rosa* cvs in a shelf-life test at EMR carried out to determine the effect of two RDI regimes applied during May to October in 2007 on shelf-life potential in 2008. During shelf-life tests, a 'wet' regime and a 'dry' regime were imposed to mimic conditions measured at several retail sites during 2007.

A short-coming in the shelf-life test identified in 2008 was that SMC values varied markedly in the 'dry' regime and fell below target values for several days resulting in severe substrate drying in both the *Cornus* and *Rosa* cvs. Therefore, in 2009, the layout of the overhead irrigation nozzles was re-designed to give more a uniform water application and SM200 soil moisture probes and GP1 data loggers were used to ensure that the target SMC values were achieved for each species in each of the 'wet' and 'dry' regimes. Manual measurements of SMC were made regularly to check that the 'wet' and 'dry' regimes were being imposed satisfactorily. The effects of the two RDI regimes imposed on *Cornus alba* and *Rosa* cvs 'Just Joey' and 'Remember Me' during 2008 were investigated. The effects of short-term RDI treatments applied towards the end of the 2008 growing season ('late RDI) to *Cornus alba* were also determined. Plant quality attributes were measured at the beginning, the middle and the end of the four-week shelf-life test.

Finally, the effect of applying RDI regimes on plants in the weeks prior to dispatch was also investigated. RDI regimes (75% and 50%) were applied to 'mature *Cornus alba* plants in 3 L pots from June until early August 2009. All plants were returned to pot capacity over several days after which the treated plants were exposed to the 'wet' and 'dry' regimes in a four-week shelf-life test. Plant quality attributes were measured at the beginning, the middle and the end of the experiment.

Results and Discussion

Imposition of RDI regimes in 2008

The volume of irrigation water applied to RDI-treated *Cornus alba* plants was either 75% or 50% of the volume of irrigation water that was applied to the well-watered controls to try to maintain an optimum SMC. Deficit irrigation was applied successfully using this approach; differences in plant-and-pot weights between the RDI and well-watered treatments were maintained during the experiment (Figure 15A). Also, whole plant transpiration rates were reduced within one week of imposing the RDI 75% and RDI 50% regimes and these differences were maintained throughout the experiment (data not shown). However, the weekly measurements made with the 'Wet' sensor showed that SMC values in the well-watered plants were quite variable (Figure 15B). The variability in SMC measured by the WET sensor at several points within a single pot can be quite high but a potential shortcoming of the GP1-automated approach is that irrigation is scheduled to all plants based on the SMC of a single pot. Therefore, the choice of a representative plant in which to place the soil moisture sensor can be critical. This problem can be circumvented to some degree by

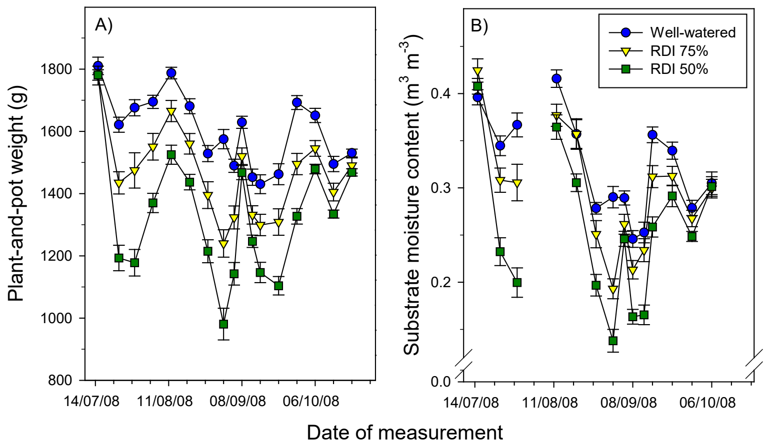

Figure 15. The effects of two RDI regimes (75% or 50%) imposed on *Cornus alba* 'Elegantissima' during July to October 2008 on A) plant-and-pot weights and B) substrate moisture content. Results are means of six replicates with associated standard error bars.

working out the relationship between the single monitored pot and the average SMC value of several experimental plants, and adjusting the SMC threshold values to maintain the average SMC in the optimum range, as was done in this experiment. Further work on optimising the GP1-automated system has been carried out in HNS 97b.

Using the Evaposensor approach, the 'late RDI' regimes applied to ***Cornus*** and the RDI 75% and RDI 50% regimes to the ***Rosa*** cvs were imposed successfully, despite frequent and heavy rainfall (***e.g.*** Figure 16). Transpiration rates of all RDI-treated plants were reduced compared to well-watered controls (data not shown) which confirmed that chemical root-to-shoot signalling was being modified by mild rootzone drying. Stem internode lengths were also reduced by the RDI treatments in ***Rosa*** cvs 'Remember Me' and 'Just Joey' (Table 1). However, stem height did not respond to either of the RDI treatments in the two Floribunda roses 'Arthur Bell' and 'Margaret Merril' (Table 1) despite RDI being imposed successfully. The reasons for this lack of response in the Floribundas are not known and further work is needed to elucidate the role of specific hormones in the control of stem height in these roses. The number and diameter of basal breaks in the Hybrid T roses was not affected by RDI but basal breaks were reduced in the Floribundas by both RDI 75% and RDI 50% regimes (data not shown). All RDI-treated plants were pulse-irrigated at the end of each experiment until SMC returned to well-watered values.

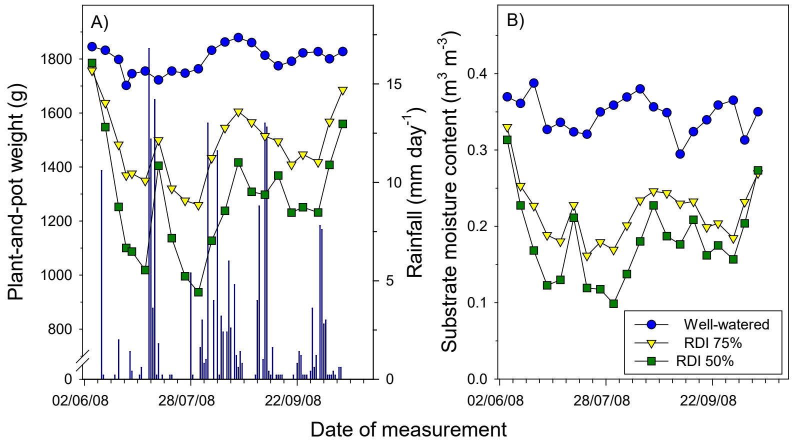

Figure 16. The effects of two RDI regimes (75% or 50%) imposed on Rosa Margaret Merril' during June to October 2008 on A) plant-and-pot weights and B) substrate moisture content. Daily rainfall throughout the experiment is also presented in A). Results are means of six replicates with associated standard error bars.

Table 1. Effect of two RDI regimes on stem height in four ***Rosa*** cvs. RDI was imposed for 131 days during the 2008 growing season. Results are means of six replicate plants with associated standard errors.

Rosa cultivar	Stem height (mm)		
	Irrigation regime		
	100%	75%	50%
'Remember Me'	370 ± 11	297 ± 21	292 ± 13
'Just Joey'	369 ± 19	323 ± 21	284 ± 31
'Arthur Bell'	399 ± 22	401 ± 15	337 ± 22
'Margaret Merril'	287 ± 27	360 ± 9	338 ± 31

Effects of RDI regimes applied during 2007 on shelf-life potential in 2008

During the six-week shelf-life test, 'wet' and 'dry' regimes were imposed on ***Cornus***, ***Photinia*** and four *Rosa* cvs that had previously remained well-watered or had been exposed to one of two RDI regimes in 2007. Regular measurements of plant-and-pot weights and SMC revealed that the extent of substrate drying varied markedly during the test in both *Cornus* and the *Rosa* cvs (Figure 17) while SMC values in *Photinia* remained high (data not shown). This highlights the difficulties faced by growers when trying to irrigate species with very different rates of water loss and, therefore, varying irrigation requirements with a single overhead system. The delivery of water from the overhead irrigation system was also very variable and so the approach was changed in 2009 to try to deliver the target SMC values more consistently.

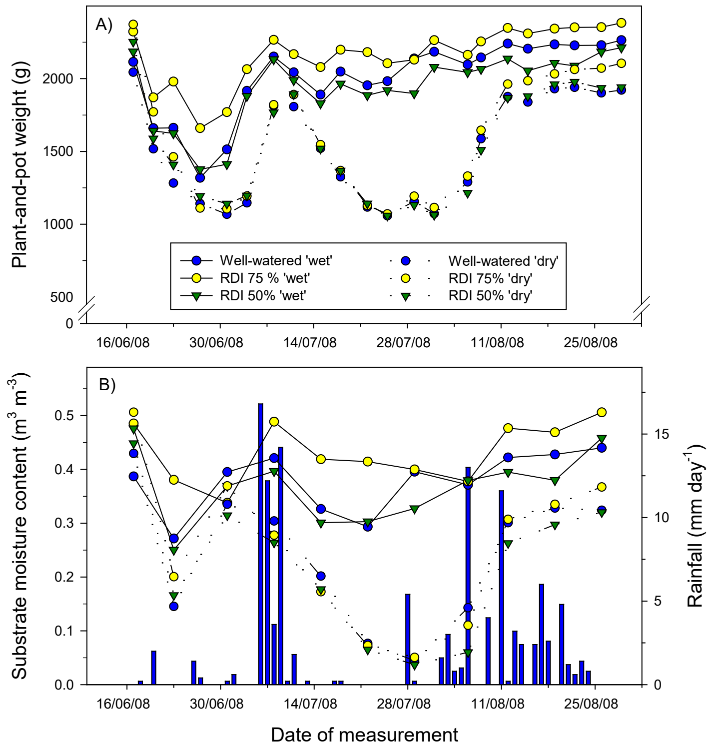

Figure 17. A) Plant-and-pot weights and B) substrate moisture contents of *Cornus alba* 'Elegantissima' during a shelf-life test in 2008. A 'wet' and a 'dry' regime were imposed during the shelf-life test to mimic conditions measured at several retail sites. Plants had previously been well-watered or exposed to one of two RDI regimes (75% or 50%) during the 2007 growing season. Daily rainfall during the shelf-life test is also presented. Results are means of six replicate plants per treatment; standard error bars have been omitted to improve clarity.

Plant quality was assessed at the end of the shelf-life test. In *Cornus*, the first visible response to drying substrate is a reddening of the leaves which is followed by desiccation and abscission if irrigation is withheld or is inadequate. These parameters were assessed along with an overall score for plant quality (Table 2). As expected, quality was higher in

Table 2. Effect of two RDI regimes applied to *Cornus alba* 'Elegantissima' during May to October in 2007 on components of quality during shelf-life tests in 2008. During shelf-life tests, a 'wet' regime and a 'dry' regime were imposed to mimic conditions measured at several retail sites during 2007. Results are means of six replicate plants per treatment with associated standard errors.

Treatment	Plant quality attribute		
	Irrigation regime		
	% red discolouration	% leaf area shrivelled	Overall quality score
Well-watered 'wet'	10 ± 3	9 ± 3	2.0 ± 0.0
RDI 75% 'wet'	17 ± 6	13 ± 3	2.0 ± 0.0
RDI 50% 'wet'	33 ± 17	9 ± 3	2.0 ± 0.0
Well-watered 'dry'	35 ± 16	44 ± 8	1.4 ± 0.2
RDI 75% 'dry'	35 ± 13	44 ± 14	1.4 ± 0.2
RDI 50% 'dry'	26 ± 16	40 ± 18	1.6 ± 0.2

plants under the 'wet' regime compared to the 'dry' regime but the scores were below those of plants deemed to be marketable (quality score = 3), even though SMC values were maintained within the target range. Overall quality of plants maintained under the 'dry' regime was poor and was presumably due to low SMC that developed in the 'dry' regime. Under the conditions of this test, there was no evidence to suggest that previous exposure to RDI improved the shelf-life potential of either *Cornus* or *Rosa* cvs. The shelf-life tests were repeated and refined in 2009 (see below).

Effects of RDI regimes applied during 2008 on shelf-life potential in 2009

RDI treatments were imposed on *Cornus* and *Rosa* cvs throughout 2008 and the plants were moved to the shelf-life benches in May 2009, after the layout of the overhead irrigation nozzles had been changed to ensure a more even water distribution. 'Wet' and 'dry' regimes were again imposed but irrigation was controlled by four separate SM200/GP1 systems. Therefore, target SMC thresholds were set for *Cornus* plants under the 'wet' or dry' regime and for Rosa cvs 'Just Joey' and 'Remember Me' under each regime. SM200 probes were placed in representative pots (Figure 18) and lower thresholds were adjusted to try to maintain SMC within the target range for each species and regime.

Figure 18. A SM200 soil moisture probe inserted into a containerised rose in a shelf-life test at EMR in 2009. Throughout the test, soil moisture sensing probes were used to trigger irrigation automatically to maintain the appropriate soil moisture contents in the 'wet' and 'dry' regimes.

This approach delivered more consistent SMC in both *Cornus* (Figure 19) and *Rosa* cvs that were maintained throughout the four-week test. Quality was assessed at the beginning, the middle and the end of the test for both *Cornus* and *Rosa* cvs 'Just Joey' and 'Remember Me'. Quality scores for *Cornus* were again highest in plants

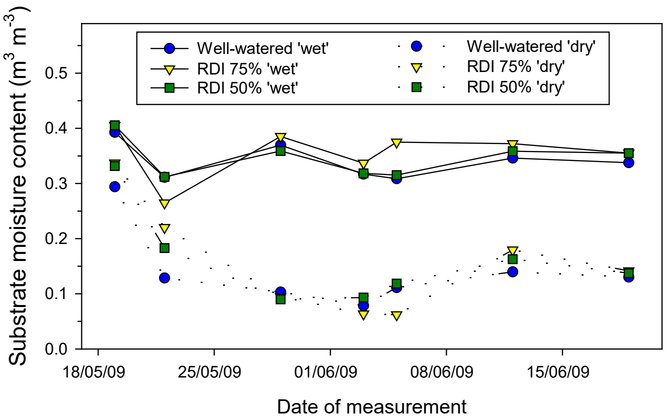

Figure 19. Substrate moisture contents of *Cornus alba* 'Elegantissima' during a shelf-life test in 2009. Plants had previously been well-watered or exposed to one of two RDI regimes (75% or 50%) during the 2008 growing season. Results are means of six replicate plants per treatment; standard error bars have been omitted to improve clarity.

maintained under the ‘wet regime (Table 3); and were classed as ’marketable (Figure 20A). However, the deterioration in quality from the beginning to the end of the four-week test was marked. This fall in quality occurred despite the effective irrigation scheduling delivered by the GP1 automated system and may have been triggered by a period of warm sunny weather at the end of May / beginning of June during which water uptake by the roots was insufficient to prevent some leaf discoloration. Again, there was no evidence to suggest that plants exposed to RDI in the previous year were better able to tolerate the dry conditions imposed in the shelf-life test (Table 3).

Table 3. Effect of two RDI regimes applied to *Cornus alba* ‘Elegantissima’ during May to October in 2008 on plant quality during shelf-life tests in 2009. During shelf-life tests, a ‘wet’ regime and a ‘dry’ regime were imposed to mimic conditions measured at several retail sites during 2007. Results are means of six replicate plants per treatment with associated standard errors.

Treatment	Overall plant quality		
	Experiment day and measurement date		
	Day 0 12/05/09	Day 23 03/06/09	Day 41 19/06/09
Well-watered ‘wet’	4.8 ± 0.1	3.3± 0.2	3.2 ± 0.2
RDI 75% ‘wet’	4.9 ± 0.1	4.0 ± 0.0	3.3 ± 0.2
RDI 50% ‘wet’	4.5 ± 0.2	3.5 ± 0.2	3.0 ± 0.3
Well-watered ‘dry’	-	3.2 ± 0.2	3.0 ± 0.0
RDI 75% ‘dry’	-	2.5 ± 0.5	2.5 ± 0.3
RDI 50% ‘dry’	-	2.8 ± 0.7	2.4 ± 0.2

The quality of the two *Rosa* cvs maintained under the ‘wet’ regime remained high throughout the shelf-life test (Figure 20B, Table 4), irrespective of previous irrigation treatments. All plants under the ‘dry’ regime were also classed as ‘marketable’ but there was no improvement in shelf-life potential in the two groups of plants previously exposed to

Figure 20. *Cornus alba* ‘Elegantissima’ and *Rosa* cvs at the end of a shelf-life test in 2009. Several components of plant quality were measured at the end of the test to determine whether previous exposure to RDI improved tolerance to stresses encountered during a simulated retailing period.

RDI (Table 4).

Table 4. Effect of two RDI regimes applied to *Rosa* 'Remember Me' during May to October in 2008 on plant quality during shelf-life tests in 2009. During shelf-life tests, a 'wet' regime and a 'dry' regime were imposed to mimic conditions measured at several retail sites during 2007. Results are means of six replicate plants per treatment with associated standard errors.

Treatment	Overall plant quality		
	Experiment day and measurement date		
	Day 0 12/05/09	Day 23 03/06/09	Day 41 19/06/09
Well-watered 'wet'	5.0 ± 0.0	4.5 ± 0.3	4.0 ± 0.0
RDI 75% 'wet'	5.0 ± 0.0	4.0 ± 0.0	3.8 ± 0.3
RDI 50% 'wet'	4.9 ± 0.1	4.5 ± 0.3	4.3 ± 0.3
Well-watered 'dry'	-	3.5 ± 0.3	3.3 ± 0.3
RDI 75% 'dry'	-	3.8 ± 0.3	3.5 ± 0.3
RDI 50% 'dry'	-	4.0 ± 0.3	3.5 ± 0.3

Effects of short-term RDI regimes on shelf-life potential

The potential benefits of applying RDI in the weeks immediately prior to dispatch were investigated using mature *Cornus alba* plants. Irrigation treatments were imposed during June and July 2009 using the GP1-automated system. Manual measurements of SMC and stomatal conductances confirmed that the RDI treatments were being imposed effectively. RDI-treated plants were then returned to pot capacity and all plants subjected to a four-week shelf-life test. At the end of the shelf-life test, the quality of plants previously treated with RDI was again similar to that of well-watered controls in both the 'wet' and 'dry' regimes (Table 5). However, stomatal conductances were reduced in the previously well-watered plants maintained under the dry regime when measured towards the end of the shelf-life test (Figure 21A) and the rate and extent of substrate drying was greater than in the two groups of plants previously treated with RDI (Figure 21B). These data suggest that the previously well-watered plants were less able to control rates of water loss when exposed to 'dry' conditions and available water was quickly used. Therefore, pre-treatment with RDI prior to dispatch may help to conserve substrate moisture content during retailing when the efficiency of irrigation applications and scheduling can be an issue.

Table 5. Effect of two short-term RDI regimes applied to mature *Cornus alba* 'Elegantissima' prior to dispatch on components of quality during shelf-life tests in August 2009. During shelf-life tests, a 'wet' regime and a 'dry' regime were imposed to mimic conditions measured at several retail sites during 2007. Results are means of six replicate plants per treatment with associated standard errors.

Treatment	Plant quality component		
	Irrigation regime		
	% red discolouration	% leaf area shrivelled	Overall quality score
Well-watered 'wet'	20 ± 5	20 ± 4	3.0 ± 0.0
RDI 75% 'wet'	24 ± 6	24 ± 5	2.9 ± 0.1
RDI 50% 'wet'	19 ± 4	25 ± 4	3.0 ± 1.9
Well-watered 'dry'	28 ± 6	34 ± 8	2.6 ± 0.2
RDI 75% 'dry'	33 ± 7	36 ± 5	2.6 ± 0.2

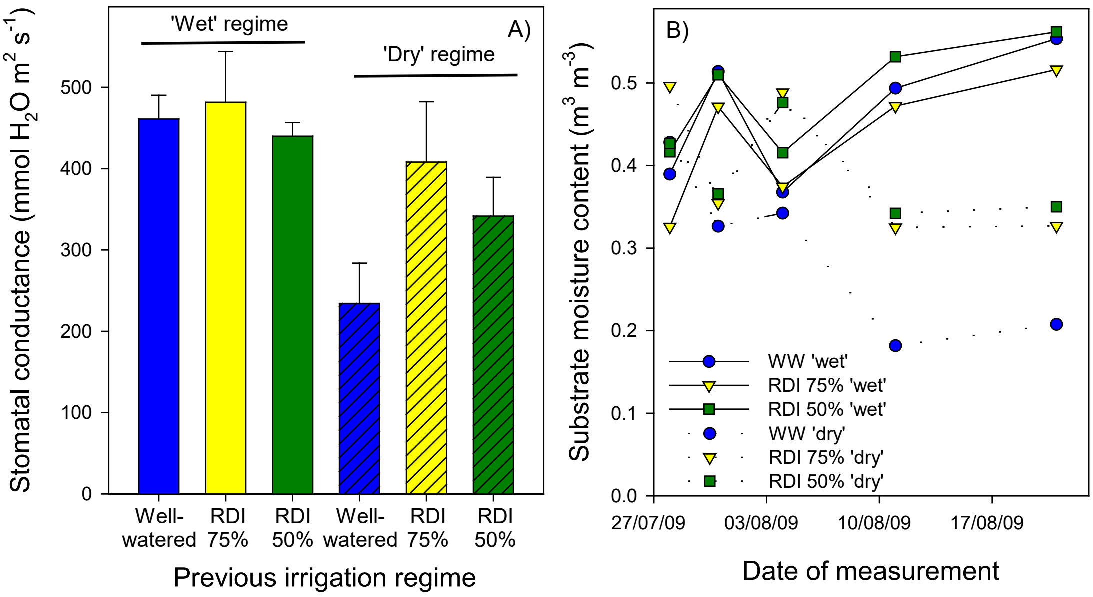

Figure 21. Effects of short-term RDI treatments on A) stomatal conductance and B substrate moisture content in Cornus alba 'Elegantissima' during a four-week shelf-life test Results are means of six replicate plants per treatment; standard error bars have been omitted from B) to improve clarity.

RDI 50% 'dry'	39 ± 9	41 ± 6	2.8 ± 0.2

Objective 4: To identify underlying mechanisms and develop strategies to improve quality (2008-2009)

Anecdotal evidence suggests that accumulations of ethylene can promote leaf drop in some *Rosa* cvs (Neal Wright - personal communication) and exposure to low concentrations of ethylene during distribution may trigger deterioration in plant quality during retailing. Dose response tests were carried out to identify the minimum concentrations of ethylene needed to trigger leaf abscission during the half-growth stage of two Hybrid-T roses and two Floribunda roses. These tests were designed to determine whether exposure to ethylene during transport and retailing could 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 would be determined. The effect of RDI on the production of, and sensitivity to, ethylene was also determined.

Materials and methods

The effects of ethylene on leaf abscission and overall plant quality were determined in dose-response tests. Preliminary tests established that exposure of *Rosa* 'Remember Me' to 20 ppm ethylene for 24 h resulted in extensive leaf yellowing and abscission (Figure 22A). Ten individual rose plants of each cv. were sealed inside airtight plastic 100 L bins and the appropriate volume of a 2% ethylene standard was introduced *via* a septum so that the ethylene concentration within the bin was 1, 5 or 10 ppm. Control plants received air only *via* the septum. All bins were then stored in the dark at 20 ºC for 24 h. Samples of gas from within the bins were withdrawn *via* the septum after 6 h and the ethylene concentration measured using a gas chromatogram fitted with a flame ionisation detector (GC-FID) to check that the final concentrations of ethylene within the bins were correct and that the bins were airtight. After 24 h, rose plants were removed and placed on mypex-covered sandbeds with full irrigation for seven days. The extent of leaf yellowing and number of leaves absconding was scored after one, four and seven days.

Figure 22. A) Effect of a 24-h exposure to 20 ppm of ethylene on leaf abscission in *Rosa* 'Remember Me'. B) Control plants were treated similarly but were not exposed to ethylene.

Rates of basal ethylene production were also measured in each of the four *Rosa* cvs immediately before the shelf-life test in 2008. Freshly excised shoot tips were sealed inside glass vials with screw lids containing rubber septa. Shoot ethylene production rates were measured 60 min after excision by head space analysis using GC-FID. Shoots were removed and weighed and ethylene production rates expressed in terms of pmoles (10^{-12} moles) of ethylene produced per kg fresh tissue weight per second (pmol kg^{-1} s^{-1}).

Results and Discussion

Rates of basal ethylene production were low and similar in each of the four *Rosa* cvs (data not shown). No effects of exposure to 1, 5, or 10 ppm ethylene for 24 h on the extent of leaf yellowing or the rate of leaf abscission were noted in any of the *Rosa* cvs (Figure 23). Ten ppm ethylene is a very high concentration and such accumulations of ethylene during transit and retailing would be very unlikely. Ethylene concentrations of between 10 and 20 ppm would be needed to trigger leaf yellowing and abscission in *Rosa* 'Remember Me'. In previous Defra-funded work, we detected ethylene concentrations no greater than 5 ppm in the depot of a major retailer. Although some *Rosa* cvs are very susceptible to this gas, the decline in quality of the cvs used in this work could not be attributed to exposure to ethylene. We were unable to carry out ethylene dose response tests on *Rosa* cvs with a notoriously poor shelf-life since these cvs had been dispatched very early in the season.

Figure 23. Rosa 'Arthur Bell' seven days after a 24-h exposure to 10 ppm ethylene. No leaf yellowing or abscission was noted in any of the ethylene dose response tests using concentrations of 1, 5 or 10 ppm ethylene.

Given the lack of any effects of ethylene on plant quality in our work, experiments designed to test the effect of blocking ethylene perception using 1-methylcyclopropane (1-MCP), a chemical inhibitor of ethylene perception, on quality and shelf-life potential were unnecessary.

Conclusions

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 and expression 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. 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, 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 (see also Cameron *et al*., 2008). 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* cvs 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 2007 also prevented RDI from being imposed effectively in the *Rosa* cvs during the first and second growth flushes and so any treatment effects on the production of basal breaks were minimised. However, RDI was imposed effectively during 2008 and the numbers of basal breaks were reduced in the Floribunda roses although basal breaking of the Hybrid T roses was not affected. Floribunda and Hybrid T roses also responded differently to RDI in terms of the effect on stem heights. The reasons for these different responses are not known but highlight the difficulties in developing a single RDI regime to improve quality in a range of HNS species.

Some species do not respond well to RDI. The hormone balance of RDI-treated plants is very different from that in well-watered plants and physiological process that are controlled by the relative concentrations of several hormones such as branch production and flower initiation can be expected to be altered. 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 pulsed irrigation during the day, our work with *Cornus* highlighted the difficulties in keeping the compost sufficiently moist in the well-watered controls to prevent marginal leaf scorching. Even when irrigation was triggered automatically to try to maintain

SMC of the well-watered controls within narrow limits, some leaf discolouration was apparent. On warm, windy days, the roots of *Cornus* may be unable to supply sufficient water to the shoots to maintain leaf water status, irrespective of how moist the compost is. If this is the case, the deterioration in quality seen during retailing will be difficult to overcome. The loss of transpirational leaf cooling resulting from stomatal closure in deficit-grown plants could b expected to increase the likelihood of leaf scorching.

Shelf-life potential

The shelf-life tests carried out at EMR in 2008 and 2009 failed to demonstrate any positive effects of previous RDI treatments on the maintenance of quality during a simulated retailing period. The lack of any effect in plants treated in the previous year may have been expected but work with other ornamental crops has shown that the tolerance to chilling stress can be bestowed four months after the end of a short-term RDI treatment. The underlying mechanisms to an RDI-induced improvement in shelf-life potential may involve enhanced antioxidant capacity or osmotic adjustment in the leaves that help to minimise the deleterious effects of progressive substrate drying. However, using RDI to pre-condition plants immediately prior to a shelf-life test slowed the rate of substrate drying when a 'dry' regime was imposed, compared to plants that were previously well-watered. Maintenance of a more favourable substrate moisture content could be expected to slow the rate of deterioration in quality over several weeks in the retail environment. Although stomatal conductance was only measured at the end of the shelf-life test, the rapid substrate drying was presumably a consequence of high stomatal conductance in plants that were previously well-watered when they were exposed to a 'dry' regime.

Practical considerations

In addition to delivering substantial water savings, results presented here demonstrate that RDI applied *via* drip irrigation has the potential to improve quality in some but not all HNS species and *Rosa* cvs. In some species, quality was maintained but in others, plant quality at market date was reduced by RDI. The effects of RDI on high value crops should first be tested before being attempted on a commercial scale. This can only be achieved satisfactorily on nurseries where the efficiency of irrigation application is high and irrigation is scheduled using approaches derived from scientific methods. Since more plants are lost due to over irrigation than to under irrigation (Knox *et al.*, 2009), HNS growers would benefit in the short-term from improvements in irrigation application efficiency and effective irrigation scheduling. Some of these issues are currently being addressed in HNS 97b. There may be benefit in applying a mild RDI regime prior to dispatch to reduce stomatal apertures so that rates of water loss and of substrate drying are reduced during the retailing phase. This may help preserve quality in some HNS species and reduce wastage in-store.

Technology Transfer

Objective 5 of the project aimed to, "communicate the results from this study to growers and to facilitate effective practical knowledge transfer to the industry". The project's knowledge transfer activities included:

1) 'How irrigation affects plant quality'. HDC News article (April 2006).
2) 'Improving the quality of Rose and Hardy Nursery Stock at East Malling Research'. Article in British Rose Growers' Association Newsletter (Summer 2006).
3) 'Improving the quality of Rose and Hardy Nursery Stock'. Project summary supplied to representatives of Homebase, B&Q, Wyevale Garden Centres, Harkness Roses, Burston Nurseries, David Austin Roses and Paul Chessum Roses.
4) Overview of project presented to the members of the Horticultural Trade Association (February 2007).
5) Several project meetings and discussions with Mr David White (Paul Chessum Roses) and Mr David Hooker (Hillier Nurseries) throughout 2007.
6) The project aims, objectives and results to date were presented to members of the Kent Horticultural Discussion during a visit to EMR (July 2007).
7) 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).
8) An overview of the project was presented to members of the HTA during a visit to EMR on 18 December 2007.
9) HDC short report 'Quality Ripe for Promotion' (February 2008).
10) 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).
11) Spoken presentation at the HDC/HTA Roses R&D Forum, NIAB, 4 December 2008
12) An overview of the project was presented at an HNS COST meeting in Angers, France (June 2007)
13) An overview of the project was presented to at an ENAR meeting in Angers, France (June 2007)
14) An article describing the objectives and results from the project is currently being prepared for submission in November 2009.

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.

ETp – 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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