Project title:	**Improving The Control And Efficiency Of Water Use In Container-Grown Hardy Ornamental Nursery Stock**
Annual report:	**Third year; March 2002**
Project number:	**HL0132LHN / HNS 97**
Authors:	**Dr Ross Cameron, Dr Richard Harrison-Murray Mr Chris Burgess Dr Sally Wilkinson Prof. William Davies Mr Martin Hodnett Mr Ken Blyth Dr David Marlow Mr Andrew Godley**
Location of Project:	**HRI-East Malling and Efford; Lancaster University, CEH, WRc, Commercial Nurseries**
Project Co-ordinators	**Mr John Woodhead**
Date project commenced:	**1 April 1999**
Date completion due:	**31 March 2003**
Key words:	**Irrigation, plant quality, container nursery stock, instrumentation**

LIST OF PARTICIPANTS

Horticulture Research International (HRI)

Centre for Ecology and Hydrology (CEH)

Lancaster University (L)

Water Research Centre (WRc)

Horticultural Development Council (HDC)

Horticultural Trades Association (HTA)

Delta-T Devices Ltd

Skye Instruments Ltd

Hillier Nurseries Ltd

Hugh Nunn Nurseryman

Johnsons of Whixley Ltd

Notcutts Ltd

Oakover Nurseries Ltd

Wyevale Nurseries

CONTENTS

PRACTICAL SECTION FOR GROWERS

Introduction

This project aims to provide a better understanding of plant water relationships in woody ornamental plants, and to improve the efficiency of water use in the commercial production of such plants. Most container nurseries rely heavily on the use of overhead irrigation, and techniques need to be developed to minimise the waste of water associated with such systems. The projects remit is to:

- Collect and analyse water use data from a number of commercial nurseries using overhead irrigation.
- Evaluate if new instrumentation can aid in the control of irrigation and reduce water use.
- Determine if irrigation can be used positively to regulate shoot development and enhance crop quality.
- Understand the mechanisms by which root-derived signals can manipulate such development.

Water use on Nurseries

During the last year further data has been collated from nurseries in an attempt to determine why the volume of water may vary to such an extent between different nurseries, and how weather patterns / geographical considerations may affect these factors. In addition, the data is providing a useful reference point for evaluating potential water savings and determining the wider economic implications of adopting more efficient or 'lean' watering regimes. Data from 2001 again implied there were relatively large differences in water use between various nurseries (up to 100% difference), although variations in crop type may partially account for this. Despite rainfall and cooler temperatures, water use across nurseries tended to be greater outside than under protection. This re-emphasises the need to minimise exposure to wind and provide as good a distribution system as possible. Nurserymen can help evaluate how accurate their own current irrigation set-up is by calculating a co-efficient of uniformity for any given bed.

Instrumentation

One key way of reducing water use on nurseries is to match irrigation more closely to the water demands (evapo-transpiration) of the crop. The amount of water lost from a crop strongly relates to the prevailing weather conditions. Developing instruments that can control irrigation and take account of variable weather is fundamental to optimising applications. In this last year, the project has focussed in on more detail on the effectiveness of evaposensors, the automatic weather station, thetaprobes and mini-tensiometers. Results were encouraging and the use of a single thetaprobe successfully enabled irrigation to be controlled automatically for outdoor beds of *Hydrangea* (Figure 1). Once the thetaprobe detected that the moisture content of the growing medium was less than a threshold value, it called for irrigation to come on automatically until a higher moisture content level was detected. The practical consequence of which was the crop being watered relatively heavily every 2-3 days. The same irrigation controller was used to manage the neighbouring *Cotinus* crop, but because water use was somewhat greater in this species, the system effectively produced a reduced deficit irrigation regime with *Cotinus*. Nevertheless, there were no adverse effects encountered suggesting that a single thetaprobe may be able to control irrigation over a number of different crops types, assuming specimens/pots are of equivalent size. The location of the thetaprobe within the crop and also within the pot is important to ensure a representative reading is obtained. The pot selected should lie in the middle to dry end of the moisture distribution for a given bed and the mini-tensiometer results suggest that the middle segment of the pot is the most suitable location for any soil-based sensor. An alternative means of determining evapo-transpiration demand and providing automatic control is using the evapo-sensor and calculating the daily integrated totals of evaporative demand. This would allow irrigation times across a number of beds to be increased or degreased on a proportion basis depending on the weather conditions over the previous 24 hours.

Controlled deficit irrigation

During 2001 it was also attempted to compare controlled deficit irrigation using overhead irrigation, both under protection and outside. In each situation a small groups of plants were weighed to determine daily water loss. In the control (100% treatment) irrigation was then applied in an attempt to bring plants back to their initial container capacity weight. In another bed of plants only 25% of this volume was applied. A layer of polythene covered the beds to allow some lateral movement of water to the base of the pots. Both plants on the 100% and 25% regimes remained relatively compact, suggesting that both systems were imposing a controlled water deficit, at least for some part of the daily cycle. In the most extreme environment (25% under protection), some plants at the edge of the bed were exposed to excessive stress and suffered some foliar damage. Therefore for such a regime to work in practice, some safety measure would need to be included. Data from the plants grown outside, however, suggests that this may possibly be accomplished by the occasional heavy watering ‘super-imposed’ on the deficit regime. Plants on the 25 % treatment outside were exposed to rainfall, which resulted in re-wetting of the growing medium for short periods, but notably this had little influence on the shoot growth. Plants remained compact and well-shaped throughout (Figure 2). Practical systems now need to be refined to ensure good growth control, yet eliminate any risk to the crop.

Root generated signals

Understanding how deficit irrigation works in regulating growth has led to the hypothesis that hormonal or other chemical signals generated in the roots control stomatal aperture in the leaves, even when water deficits may not occur in the foliar parts of the plants *per se*. The precise mechanism of this signal remains to be determined, but may involve alterations in the pH of the xylem sap. Logical thinking would suggest therefore, that if we can control the pH of the xylem directly, we may be able to close stomata and reduce growth rates at certain key stages in the production cycle. Recent research has investigated the application of ammonium chloride to the rootzone as a tool to regulate the pH, reduce stomatal conductance and act both as a ‘brake’ to excessive shoot growth and also reduce plant water use. Results are at a preliminary stage, but early findings suggest that certain compounds may have the potential to control crop growth effectively through the regulation of stomatal behaviour.

Figure 1. Irrigation of Hydrangea and Cotinus at HRI-Efford controlled by a single thetaprobe

Figure 2. Uniform crop development on a reduced irrigation regime at HRI-East Malling. (note pot holders to avoid wind-throw of pots)

Industry-relevant results include:

- **Comparisons between different nurseries suggest that savings in water can be accomplished immediately, by following a 'best practice approach'.**

- **Water use was often reduced when plants were grown under protection compared to outside beds.**

- **The thetaprobe appears to have potential as a very effective irrigation controller. One probe controlled the irrigation for an entire bed with a relatively uniform crop being produced.**

- **Reduced levels of irrigation, in addition to having a positive effect on plant habit, appear to have the potential to reduce the presence of weeds in the crop.**

- **Certain chemical compounds e.g. ammonium chloride, may have the potential to regulate stomatal control, regulate growth and help reduce water loss from plants.**

- **Using a modify system of estimating water demand i.e. the 'target weight' approach it was feasible to implement RDI growth controlling regimes using overhead irrigation.**

- **Rainfall did not significantly influence the response to the RDI regime when plants were grown outside.**

SCIENCE SECTION

CONTROLLING PLANT GROWTH AND SHAPE THROUGH REGULATED DEFICIT IRRIGATION (RDI)

OBJECTIVE 2

HRI-EAST MALLING

Relevant milestones

2.8 Refine and re-test the most promising RDI treatments from year 2 to control growth in model species. Implement experiments under protected and non-protected situations.

2.9 Set up similar experiments to 2.4 and 2.5 to determine the effect of localised application of water (e.g. via dripper) compared to more uniform application.

Previous experiments on RDI at East Malling had been implemented via drip irrigation systems. These had yielded encouraging results in terms of reduced water use and improved plant quality. Unfortunately, drip irrigation is not extensively used in HNS production and the majority of crops in this sector are irrigated using overhead sprinklers. Therefore, one of the primary objectives of this year's programme was to evaluate if RDI could be implemented using an overhead system, and how this would affect crop quality and uniformity. A second objective was to further evaluate the influence of localised watering using the Partial Root Drying (PRD) technique developed by Lancaster University, and compare physiological and growth responses to both that of RDI and uniformly, well-watered plants.

Experiment 1. Regulating plant growth using overhead irrigation

In previous RDI experiments where water was applied to the crop via drip irrigation, a number of reference plants were located within the crop and these were weighed, then hand watered to determine the potential evapotranspiration (ETp) value. When using overhead irrigation it was not feasible to repeat this system, as water from the sprinklers would interfere with the precise weight measurements of the reference plants. Therefore, a new system for determining daily water demand was developed. At the start of the experiment, reference plants were brought to container capacity and weighed. The mean value for these container capacity weights was then used as a 'target' weight. By calculating the application rate of the sprinklers over each individual bed, (e.g. how much water was deposited in a pot over a given time period), the amount of irrigation required to bring plants back to their target weight could be related to time of watering. The system was less precise than its predecessor, but had reduced labour inputs and was robust enough to account for any discrepancies between the target weight and the actual volume of water applied. For example, if the target weight failed to be fully met in day 1, a proportional increase (larger weight difference) in the following day's irrigation would compensate for this.

The system was tested both under protection in a polytunnel and on a bed outdoors. In an attempt to try and relate the system to that used in commercial situations, yet still provide the maximum amount of information, approaches differed slightly between the protected and outdoor environments:

Outdoors – Plants were placed on beds covered with impermeable polythene overlaid with mypex. The bases of the beds were uneven, and as in commercial conditions localised puddling could occur in certain locations. Irrigation was provided by rotary sprinklers and as there were no windbreaks around the beds, the irrigation could drift significantly on windy days. The presence of the polythene base however, allowed some lateral movement of water between the pots and across the beds.

Polytunnel – Plants were placed on capillary matting overlaid with perforated polythene (the latter to allow water movement to the base of pots, but inhibit moss and liverwort growth). Six jet-sprinklers (stream and feather) were placed around each bed, with the nozzles directed into the bed and to minimise the amount of spray falling on the paths. Application rates were 360 litres per bed per hour.

Reference plants were brought to container capacity and randomly distributed within the beds that were to form the basis of the 100% treatment. These plants were weighed daily and the volume of water required to bring them back to the target weight calculated (i.e. applying 100% of target weight). There was a total of 45 plants per bed (including 4 reference plants) spaced at approx. 20 cm apart. To increase the stability of plants grown outdoors these were placed in pot carriers. All plants were pinched twice before potting with no further pruning.

In addition to 100% application, other beds were set-up in the same manner, but only 25% of the volume of water applied (this % was reduced in stages over 2-3 weeks, i.e. 50%, then 33% before being maintained at 25%). Experiments were carried out using *Forsythia* and *Cotinus*, with the daily evapotranspiration demand for each species being calculated independently. Plants were assessed for viability, foliar injury, height and number of laterals.

Experimental summary = 2 Species x 2 Environments x 2 Irrigation regimes.

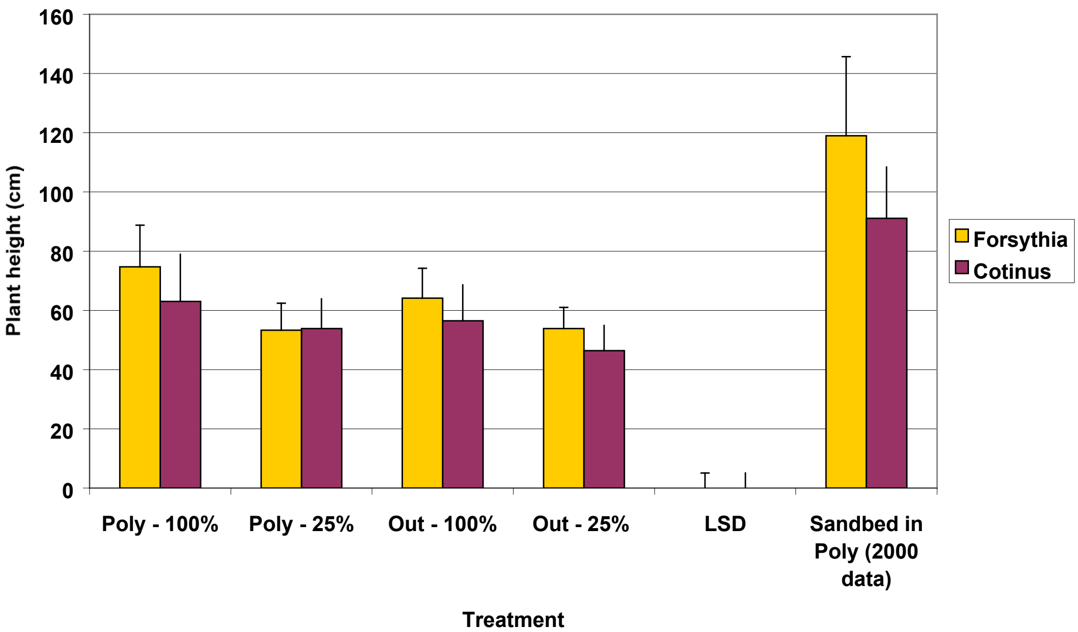
Results showed that exposing plants to the severely restricted irrigation (25%) resulted in foliar injury to some of the plants in the polytunnel (Table 2.1). Injury was restricted to those plants at the edge of the bed, and was generally manifested as necrotic lesions on older leaves. It was noted that plants grown under the 25% had considerably less weed growth compared to the plants on the 100% treatment.

Placing plants on the 25% treatment reduced plant height compared to the 100% treatment, but plant quality was good in both treatments, with relatively compact-well shaped plants being produced. (Figure 2. 1 compared heights to data for similarly aged plants from the previous season, where these had been kept well-watered on a sand bed). The small standard deviation bars associated with each treatment reflect the relative uniformity of the crop produced under each overhead system. Plants were well-branched with little variation between treatments (Figure 2.2).

Table 2.1. Rates of survival, foliar injury and weed presence within different irrigation treatments.

	Treat	% Survival	% With some foliar injury	% With weeds present
Forsythia	Poly 100%	100	0	47.5
	Poly 25%	100	11.1	2.5
	Out 100%	100	0	28.9
	Out 25%	100	0	2.2
Cotinus	Poly 100%	97.5	0	87.5
	Poly 25%	100	6.1	22.5
	Out 100%	100	0	37.8
	Out 25%	97.8	0	6.7

Figure 2.1. Mean plant height and standard deviation of plants grown either in a polytunnel or outside with overhead irrigation applied to either 100% or 25% of target weight. Comparisons to plants grown on wet sandbeds in previous year.



Interestingly, those plants grown in the 25% treatment outside (arguably the best quality of all the treatments), experienced relatively large fluctuations in their water availability during the season (Figures 2.3 and 2.4). For example in *Forsythia*, weights varied between 640g to 1300g and this related to variations in rainfall. Extra irrigation was applied to plants in the 25% treatment in the polytunnel after 6 September, to avoid excessive dehydration of the medium and to reduce the risk of foliar injury.

Figure 2.2. Mean number of laterals per plant, grown either in a polytunnel or outside with overhead irrigation applied to either 100% or 25% of target weight. Comparisons to plants grown on wet sandbeds in previous year.

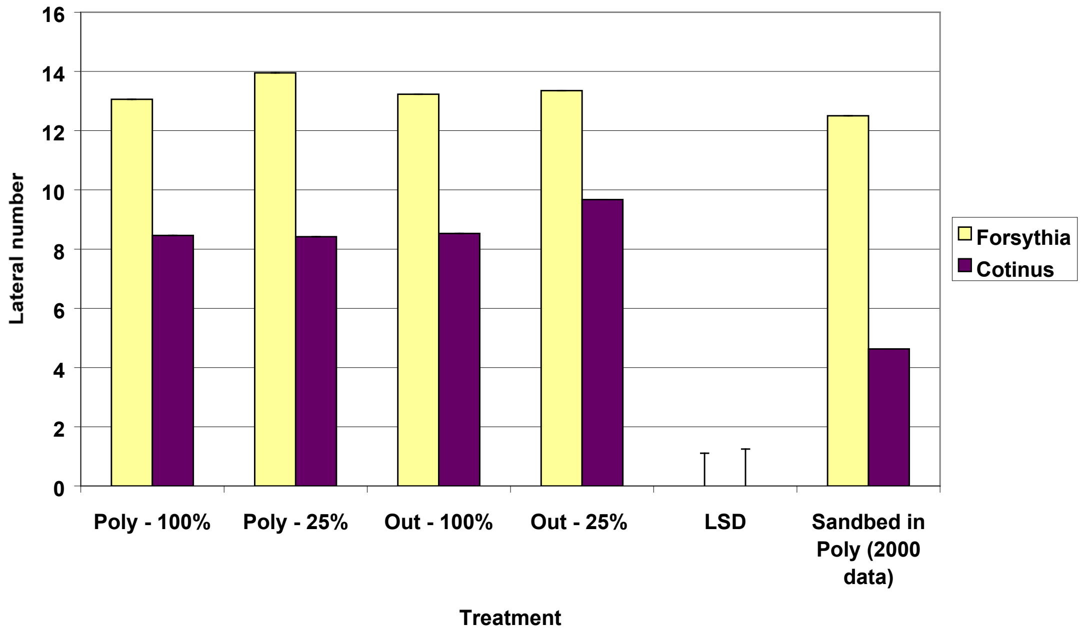


Figure 2.3. Gravimetric data (pot/plant weight) of *Forsythia* during the growing season. Plants grown either in a polytunnel or outside with overhead irrigation applied to either 100% or 25% of target weight.

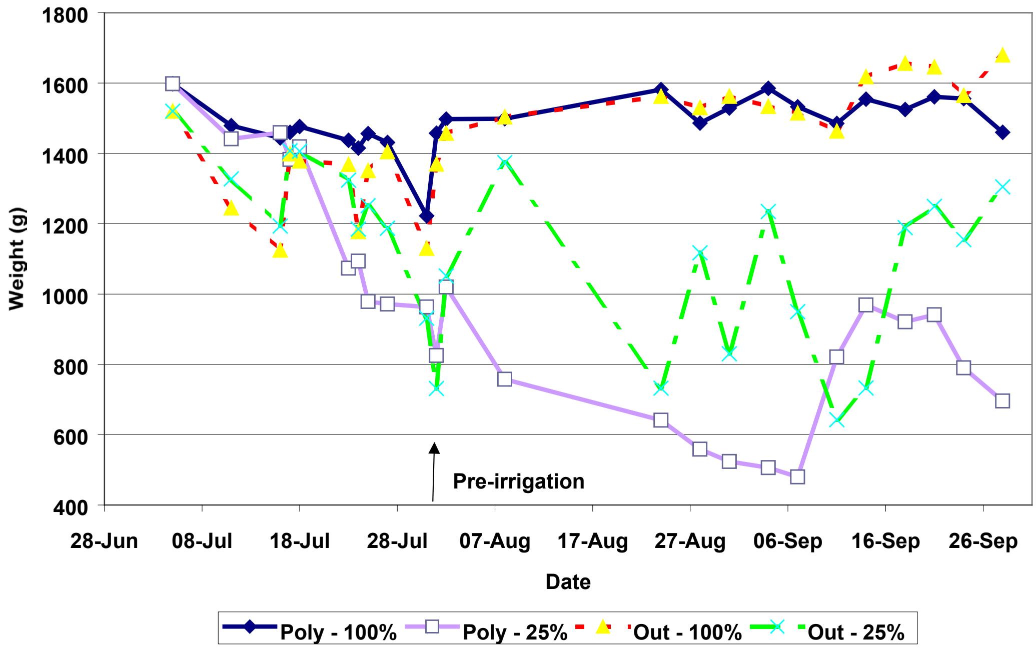
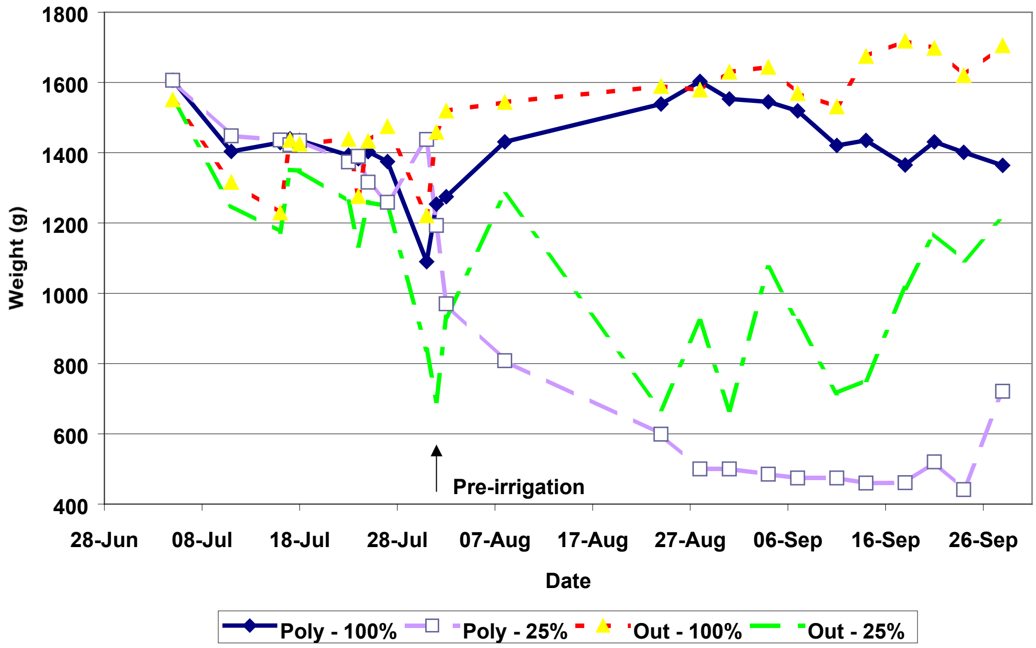


Figure 2.4. Gravimetric data (pot/plant weight) of *Cotinus* during the growing season. Plants grown either in a polytunnel or outside with overhead irrigation applied to either 100% or 25% of target weight.



Concluding points

These initial attempts to control growth via overhead irrigation have yielded some surprising results. The use of RDI in protected environments appears to be feasible, but it may be that some safety mechanism is required to counteract the effects due to non-uniform application of water and variations in demand within the crop. This may involve the provision of an occasional heavy watering to re-establish a wet growing medium across the crop. Data collected from the plants grown outside suggest this may be possible. These specimens maintained a compact and uniform growth habit, despite being exposed to episodes of heavy rain, which brought the medium back to container capacity. Future research should explore the potential to develop irrigation schedules that combine both periods of restricted application to control growth, yet intermittent periods of generous watering to re-establish more uniform water availability. Such wetting periods may be relatively infrequent, e.g. twice in an entire growing season, however, determining exactly what the appropriate balance of wetting and drying episodes is, needs to be investigated.

Experiment 2. Localised water application

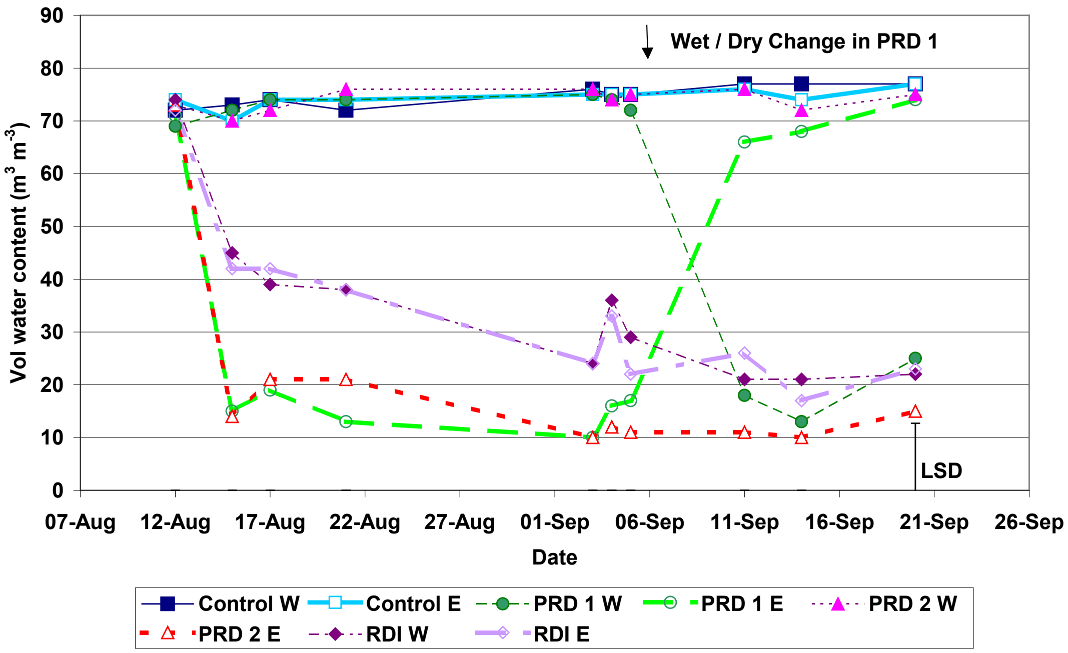
One-year-old plants of *Cotinus* and *Forsythia* were removed from 7cm pots in April and had their roots carefully teased into two parts. Each part was placed into a 9 cm pot and the pots held together with pegs to provide a 'split-pot' technique. Plants were left for 8 weeks to allow sufficient root development into each pot before being exposed to irrigation treatments.

Irrigation was provided by drip line and there were four treatments implemented:

Well-watered control = (200% ETp, applied to both pots)
RDI = (50% ETp applied to both pots)
PRD 1 = (200% ETp applied to one pot only {west side}, but the well-watered pot altered after 3 weeks {east side}).
PRD 2 = (200% ETp applied to one pot only throughout {west side throughout}).

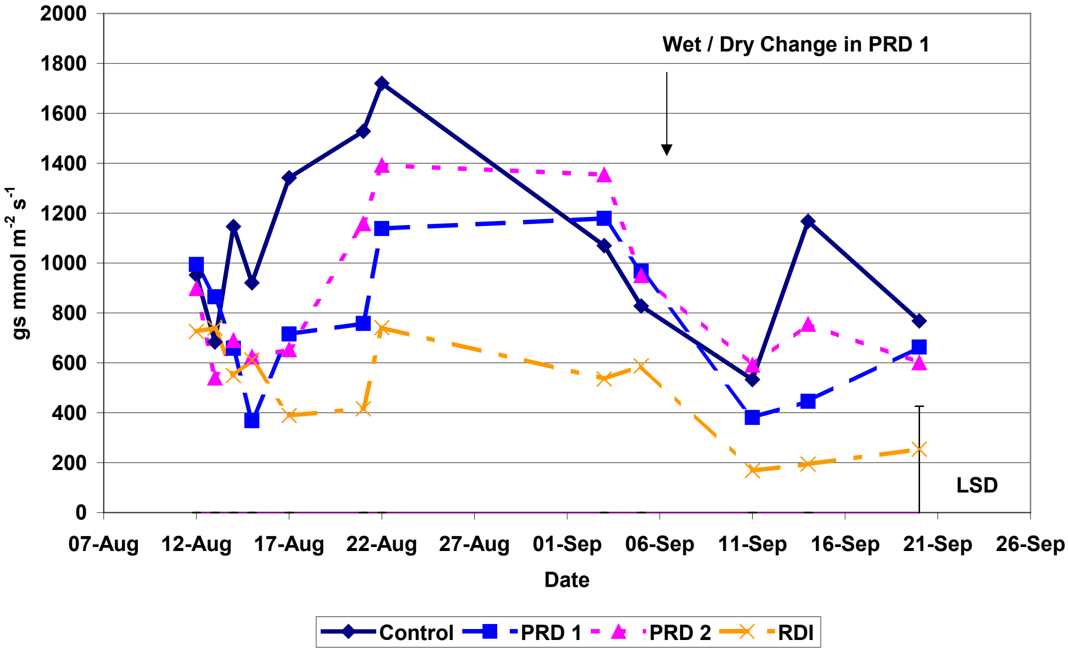
Physiological studies were carried out principally on the *Forsythia* plants. Thetaprobe data showed that the well-watered pots remained wet throughout. (Figure 2.5). Drying was rapid in the non-watered pots of the PRD treatments. In the RDI treatment initial drying was also quite rapid, followed by a period of much slower drying from 17 August onwards. Swapping the drippers between pots in the PRD 1 treatment resulted in a quick transition of the water status of the east and west positioned pots.

Figure 2.5. Water content (thetaprobe readings) in *Forsythia* as affected by 'split-pot' (west v east pots) irrigation treatments



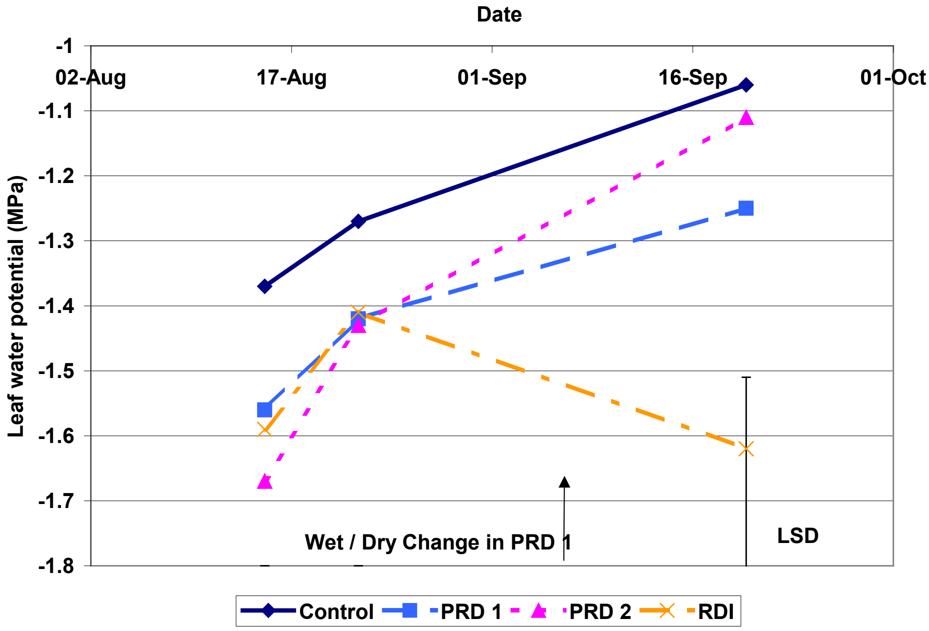
During the early stages of the experiment, both the RDI and PRD treatments reduced stomatal conductance compared to control plants (Figure 2.6), although daily variations within any treatment could be quite large. By early September values in the control plants had dropped relative to the PRD treatments (differences not significant), but showed a brief peak again around 15 September. Stomatal conductance was always lower in the RDI treatments than other treatments from 17 August onwards, although differences were only significant on occasions. Notably, there were no significant differences between the two PRD treatments, even after the drippers had been swapped on the PRD 1 treatment.

Figure 2.6. Stomatal conductance in *Forsythia* as affected by 'split-pot' irrigation treatments



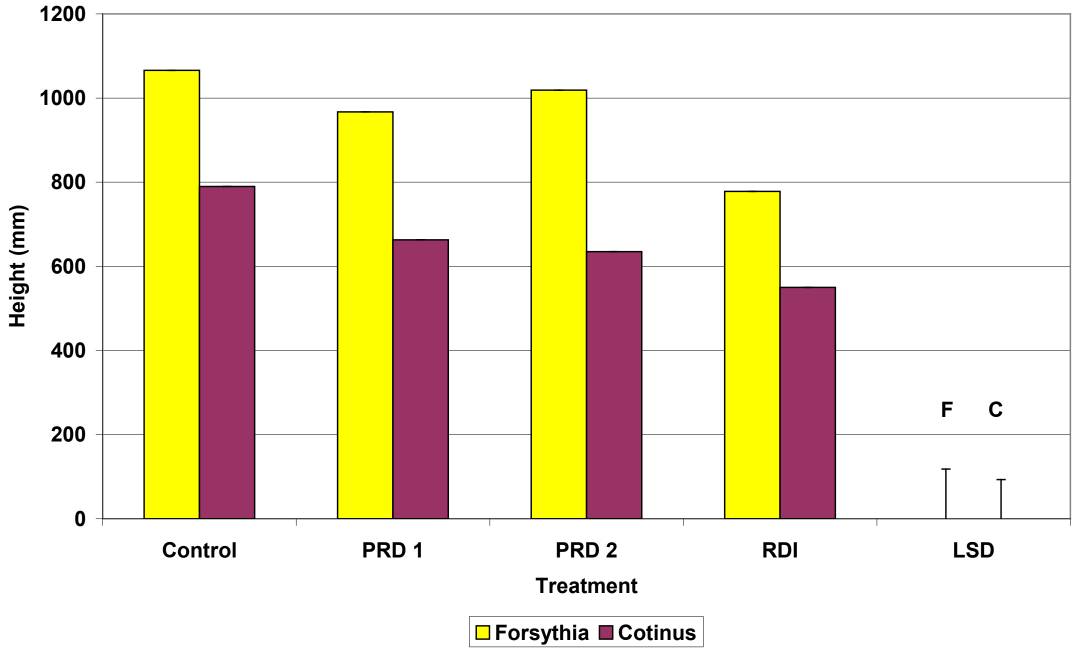
Leaf water potentials were generally most negative in mid August, reflecting the increased evaporative demand at this time (Figure 2.7). The lowest values recorded on 15 August were associated with the PRD and RDI treatments (PRD 1 being significantly lower than controls). At the later date of 20 September, there were no significant differences between PRD and control plants, however, very low potentials were observed in the RDI treatment.

Figure 2.7. Leaf water potential in *Forsythia* as affected by 'split-pot' irrigation treatments



Plants in the PRD treatments in *Forsythia* were smaller than control plants, although differences were not significant (Figure 2.8). Plants in the RDI treatment were significantly smaller than both controls and RDI treatments. Similar trends were apparent in *Cotinus* (Figure 2.8), although in this case plants in the PRD treatments had significantly reduced final heights than controls. In both species, there was no clear distinction between PRD 1 and PRD 2 treatments.

Figure 2.8. Final plant height in *Forsythia* and *Cotinus* as affected by 'split-pot' irrigation treatments



Concluding points

The localised application of water and the use of PRD resulted in a reduction in stomatal conductance and a subsequent reduction in growth. The growth reduction, however, was not as marked as that of RDI. A possible explanation of this is that the roots exposed to the dry regime either became too dry, or became dry so quickly that the root signal from them became weakened over time or was relatively transient in its effect (i.e. present at the start of the experiment only). Ironically, the occasional re-wetting of the dry zone may be a mechanism to offset this, by maintaining some transpiration from the roots and thereby allowing the root generated signalled to be transported to the shoot more effectively. Further investigations should aim to develop practical techniques that maintain the PRD effect for a more prolonged period. Possibly, some sort for of pulse irrigation system may be required.

TO INVESTIGATE THE EFFECTS OF ROOT-GENERATED ABA AND CO-FACTORS (XYLEM pH) ON GROWTH AND FUNCTIONING OF CONTAINER-GROWN PLANTS

OBJECTIVE 3

LANCASTER UNIVERSITY

Effect of added nutrients on responses of *Forsythia* plants to soil drying and the aerial environment.

Relevant milestones

3.5 Compare "split-pot", and conventional drought treatments for strength of ABA or pH signals and ability to influence those key components of growth identified in previous years (complete – see report II from 2000).

3.6 Investigate the possibility that simple modification of the nutrient status of the substrate will alter xylem sap pH, and thereby increase the strength of the root-generated signal to the shoot (good progress – see below).

Introduction

The ideology behind the experiment is that there are some indications in the literature that certain compounds, whether naturally present in soils or added via fertigation, can either directly or indirectly influence the pH of the xylem sap within some plant species (reviewed by Wilkinson and Davies 2002: ABA-based chemical signalling: the co-ordination of responses to stress in plants. Plant, Cell and Environment 25, 195-210).

Why might it be advantageous to be able manipulate plant xylem sap pH? Previous work within this project has shown how soil drying or the aerial climate can influence the pH of the xylem sap within three hardy ornamental species, and that the pH change might be (part of) the chemical signal that induces the well-known effects of soil drying: slower growth and/or reduced stomatal aperture, which enable plants to retain water as soil or air dries (see reports I and II). If we can induce changes in sap pH (or [ABA]) independently of changes in the environment (soil or air drying), we may be able to rear plants that use less water and require less frequent pruning, which are therefore cheaper to produce at the scale of the nursery.

Two other techniques (explored within this project), which have already been shown to achieve the same end product (plants that use less water with bushier growth habit), are based on supplying limiting volumes of water to the plants, in order to switch on their chemical signalling systems (increasing ABA, changing xylem pH). However these techniques have potential pit-falls. RDI may affect plant water status before the chemical signals are strong enough to close stomata and reduce growth, which could induce lesions or reduce leaf size, thereby adversely affecting plant aesthetics and even survival rates (although in the three study species used so far these effects have been very minor). PRD has the advantage of maintaining favourable plant water status at limiting water supply rates, whilst strongly inducing the plant's chemical responses to drying soil. However the technique may be difficult to implement on a large scale and may only be cost-effective during the growth of larger tree species.

In 1999 we found that drying the soil around *Forsythia* roots acidified the pH of the xylem sap in the shoots of the plants, which signalled stomata to close and shoots to slow their growth. Since there is some evidence in the literature that addition of ammonium chloride (A) to soil around plant roots can acidify xylem sap and increase root ABA loading to the xylem, we hoped to show that this treatment would close stomata and reduce growth without having to dry the soil down to the extent needed in 1999, whereby shoot water deficits were simultaneously induced; or without having to implement the PRD technique. In addition in both 1999 and 2000 we found that increases in PPFD (or VPD) increased xylem sap pH in *Hydrangea* and *Forsythia* leaves independently of soil-drying-induced effects on pH, and that alkalisation correlated with closed stomata and reduced growth rates. Since some evidence has shown that potassium bicarbonate (B) alkalises xylem sap when supplied as a solution to the soil, we hoped to artificially induce the responses described above by supplying this compound to plants experiencing non-limiting PPFDs. However we had to assume that the putative bicarbonate-induced pH change would penetrate all the way up the length of the xylem vessels of the shoots and reach the leaf apoplast (from where we believe the PPFD-induced pH changes to originate), if this manipulation were to be a success (potentially a tall order).

It is hoped that by treating plants with A or B, or a mixture of both as described below, we may be able to switch on the signalling mechanisms that plants normally only use when their roots or leaves encounter drying soil or air (increased ABA production and/or changes in xylem sap pH). Stomata may close and shoot extension rates may be reduced earlier in a soil or air drying cycle, or when plants are watered at a greater % ETp than is normally required to generate the chemical signals described above. The advantage of this system, if it were successful, would be that chemical signalling could be switched on independently of the environment. Shoot water deficits would never be generated, and plants would never be taken anywhere near the "edge", beyond which a single missed day's irrigation, for whatever reason, could result in catastrophic loss of stock.

Methods

Forsythia x *intermedia* cv Lynwood plants in 3 litre pots in a poly tunnel were irrigated by hand daily in one of the following ways:

1) Well-watered control: 300ml water.
2) RDI control: 150ml water.
3) RDI NH_4Cl (A): 150 ml 8mM A.
4) RDI $KHCO_3$ (B): 150ml 8mM B.
5) Well-watered NH_4Cl + $KHCO_3$ (A + B): 300ml 8mM A + B.
6) RDI NH_4Cl + $KHCO_3$ (A + B): 150ml 8mM A + B.

Irrigation took place between 5 and 6pm daily from 10th July to 29th August. The *Forsythia* plants were approximately 40-50cm tall with 3-4 main shoots at the start of the experiment, and approximately 70-80cm tall at the end. For the last 2-3 weeks well-watered plants received 400ml and RDI's received 200ml of the appropriate irrigation solution.

To analyse the effects of the treatments described above on chemical and physiological responses in *Forsythia*, the following measurements were taken approximately every 5-6 days from 10th July to 29th August 2001 in 3 replicates per treatment per day:

1) 1pm: soil moisture.
2) 1.30pm: stomatal conductance (leaves 2, 3 and 5), PPFD, leaf surface temperature, relative humidity.
3) 2.30pm: collected mature and immature leaves for bulk tissue ABA analysis.
4) 3pm: a) weighed mature and immature leaves for leaf relative water content, b) measured shoot water potential, c) measured xylem sap pH expressed at several over-pressures; and d) collected sap for xylem ABA analysis.
5) A separate set of plants were treated with all 4 nutrient combinations (controls, A, B and A+B) under full well-watered irrigation, under RDI *and* under PRD (3 replicates per treatment). At the end of the experimental period the following measurements were taken for each plant: soil moisture, leaf length (youngest 9-10 on the largest shoot), internode lengths (youngest 9-10 on the largest shoot), total shoot length (of the largest shoot); and shoot number.

A second experiment was conducted in 2001 on *Hydrangea macrophylla* cv Bluewave plants growing in a poly tunnel split into shaded and non-shaded sections, in order to further explore the effects of PPFD on xylem sap pH, stomatal conductance and growth described in earlier reports (data analysis incomplete).

Results

The first indication that putative pH-changing compounds may have closed stomata in *Forsythia* leaves in "wetter" soil than normal is shown in Figure 3.1: compared to well-watered controls (water only), a combination of A+B at non-limiting irrigation reduced the level of mean stomatal conductance, at least in the first half of the experiment (Fig 3.1A). The same effect can be seen if we correlate individual plant soil moistures against stomatal conductance (gs). As expected at the "wetter" end of the soil moisture spectrum (RHS) stomata gradually close (gs gradually decreases) as soil dries in controls (Fig 3.1B). However in the presence of A+B stomata are already closed in wet soil, so the usual correlation between soil moisture and gs is no longer seen (Fig 3.1C). Treatment A+B may therefore be a potential "water-saving" compound. However effects of A+B on plant growth were very different to its effects on stomatal aperture:

In the presence of A+B well-watered *Forsythia* plants had increased growth rates: both leaf area (Fig 3.2) and shoot lengths (Fig 3.3A) were greater than in control plants by the end of the experimental period. It is therefore unlikely that water would be saved during the production of these plants due to the larger growth habit induced by this nutrient combination (although this itself is a very interesting finding and may be extremely beneficial in other areas of the industry, such as when it is necessary to force plants on). However Figures 3.2-3.4 also show a separate and very

Figure 3.1 A

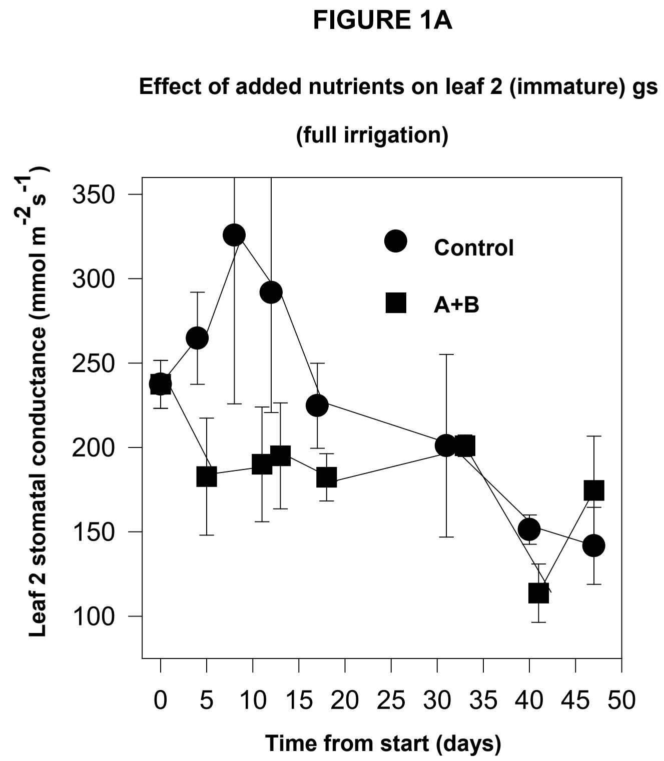


Figure 3.1 B

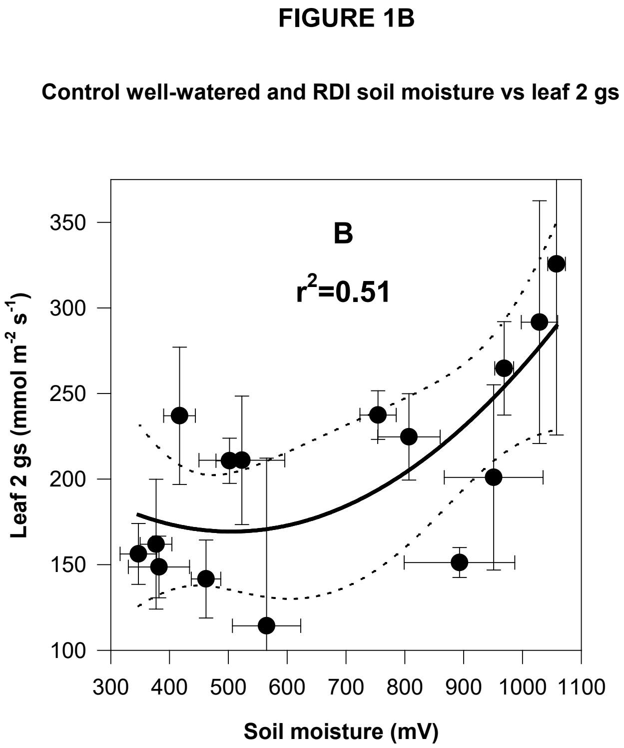
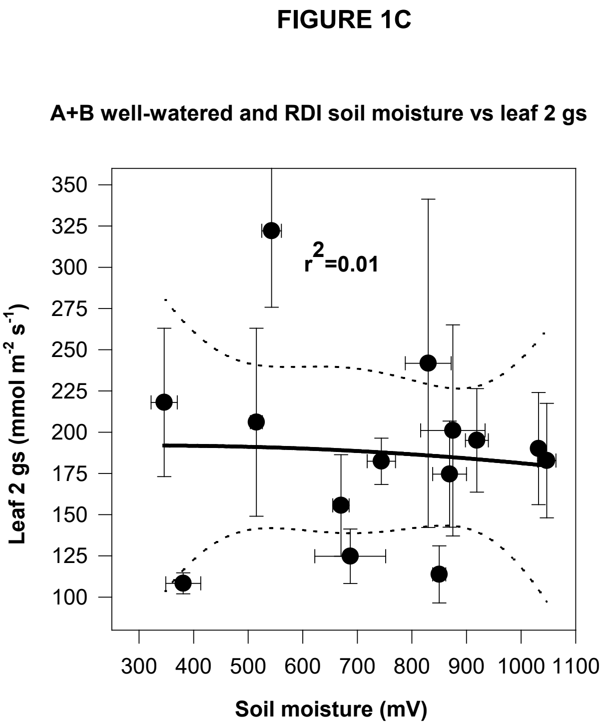


Figure 3.1 C



promising series of results: under treatment A (NH_4Cl) at full irrigation leaves grew more slowly than in controls (Fig 3.2), the ratio of dominant to subordinate shoots was decreased (Fig 3.3B), and internode extension rate was reduced (Fig 3.4). All of these effects lead to a reduction in the surface area from which a plant can lose water, and are "water-saving" traits. Our next step is therefore to determine whether A alone, like treatment A+B, also induces stomatal closure at the wetter end of the soil moisture spectrum. Unfortunately the RDI treatments used in 2001 were abrupt rather than gradual, and consequently we have no stomatal conductance data for the "wetter" end of the soil moisture spectrum in the presence of A alone or B alone.

How do A+B combined induce stomatal closure in wet soil? How does A reduce leaf and internode extension rate? Is it because A acidifies xylem sap as predicted, or because it increases ABA signalling from roots to shoots?

We examined the relationship between soil moisture and pH. As usual (see previous reports) decreasing soil moisture decreased xylem sap pH in controls at the wetter end of the spectrum (Fig 3.5A). However contrary to predictions A+B did not acidify xylem in the wettest soil (Fig 3.5B) – sap from plants grown in the wettest soil was approximately the same pH as that extracted from controls (5.8), and sap pH decreased as normal as soil dried. So A+B must close stomata in wet soil by another mechanism – probably by increasing xylem [ABA], and we will soon be in a position to confirm this hypothesis.

Unfortunately there were not enough data points to determine pH changes in the sap of plants growing in A alone or B alone as soil dried at the wetter end of the soil moisture spectrum, however it must be noted that in the presence of A alone and B alone sap pH dramatically re-alkalised in very dry soil (Figs 3.5C and D). This occurred despite the prediction that A would acidify xylem sap, and confirmed the prediction that B would alkalise it.

A tentative prediction at this point would be that the closure of stomata in wet soil seen in the presence of A+B probably also occurs in the presence of A alone (a water-saving candidate compound), as a result of its affect to increase xylem [ABA], rather than through any effects of A to acidify xylem sap pH in wet soil as predicted (although more data for A only in wet soil is needed). This may also explain effects of treatment A on plant growth characteristics, however more data is required before we can correlate growth rates with either changes in [ABA] or xylem pH.

Xylem sap pH is nicely correlated to conductance in controls as expected (Fig 3.6A), and this relationship no longer occurs in the presence of any combination of the nutrient compounds tested (A+B used as an example: Fig 3.6B). Changing the way soil drying affects xylem sap pH seems to destroy a relationship between pH and stomatal aperture and soil moisture and stomatal aperture (only seen in the presence of controls). However a lot more data is required before we can be more specific about whether it is a nutrient-induced xylem pH change that is the cause of the de-coupling of soil moisture and stomatal aperture, and/or a change in [ABA], or indeed something else.

Conclusions

In order to produce a more compact plants that grow more slowly (with more closed stomata) and which therefore require less water, it would seem that treatment A seems the most promising. We have shown here that it reduced the surface area from which plants may lose water, and other data described here has enabled us to predict that treatment A also gives rise to more closed stomata in wetter soil than in controls (as in treatment A+B). We believe all these beneficial effects of A result from its induction of increased [ABA] in the xylem sap, and not from any changes in xylem sap pH that we predicted that it might have induced. Changes in xylem pH were induced by the compounds only in very dry soil.

Figure 3.2

FIGURE 2

Well-watered plants

Effect of nutrients on leaf length profile

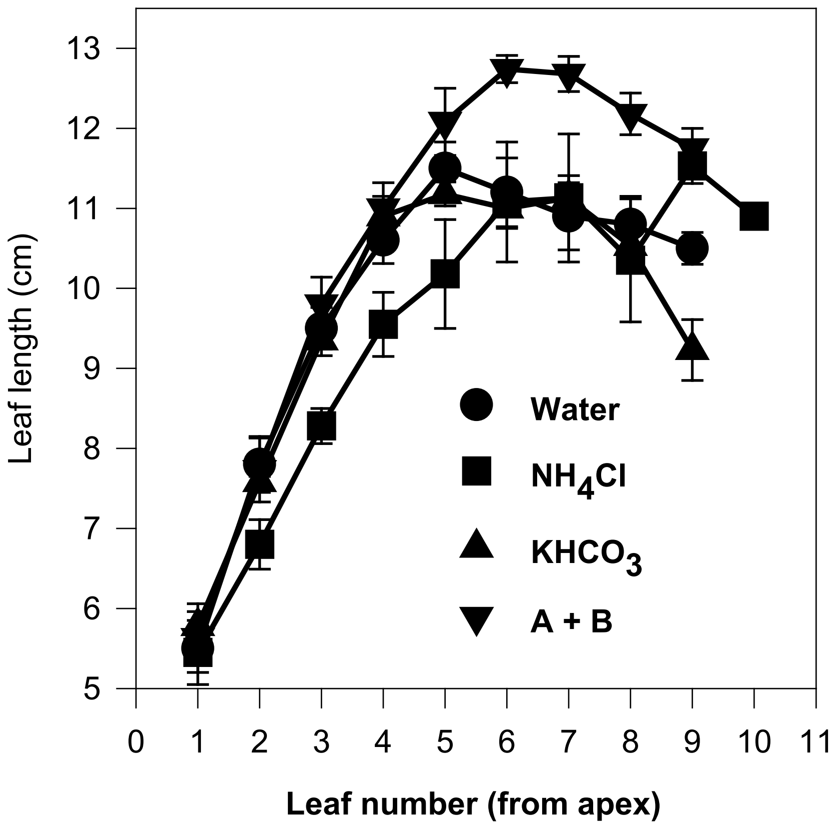
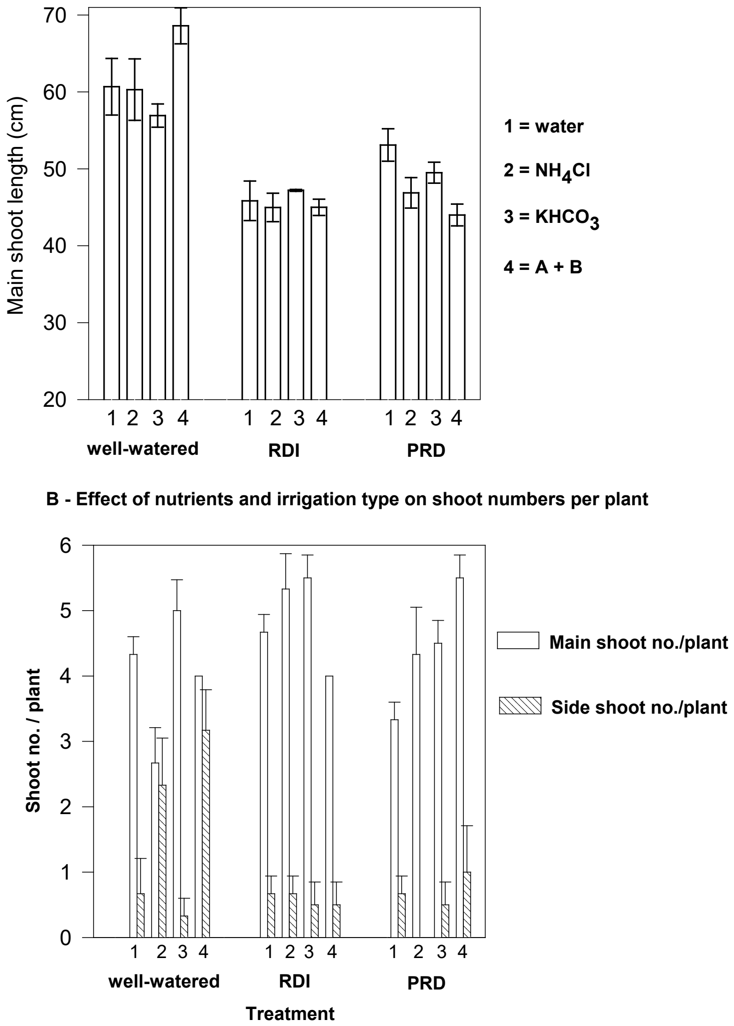


Figure 3.3

FIGURE 3

A - Effect of nutrients and irrigation type on shoot length



<u>**Figure 3.4**</u>

FIGURE 4

Well-watered

Effect of nutrients on internode length profile

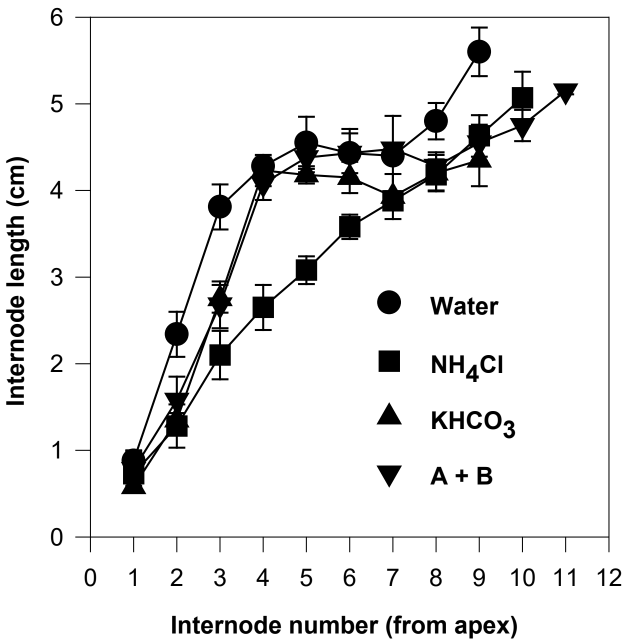


Figure 3.5 A

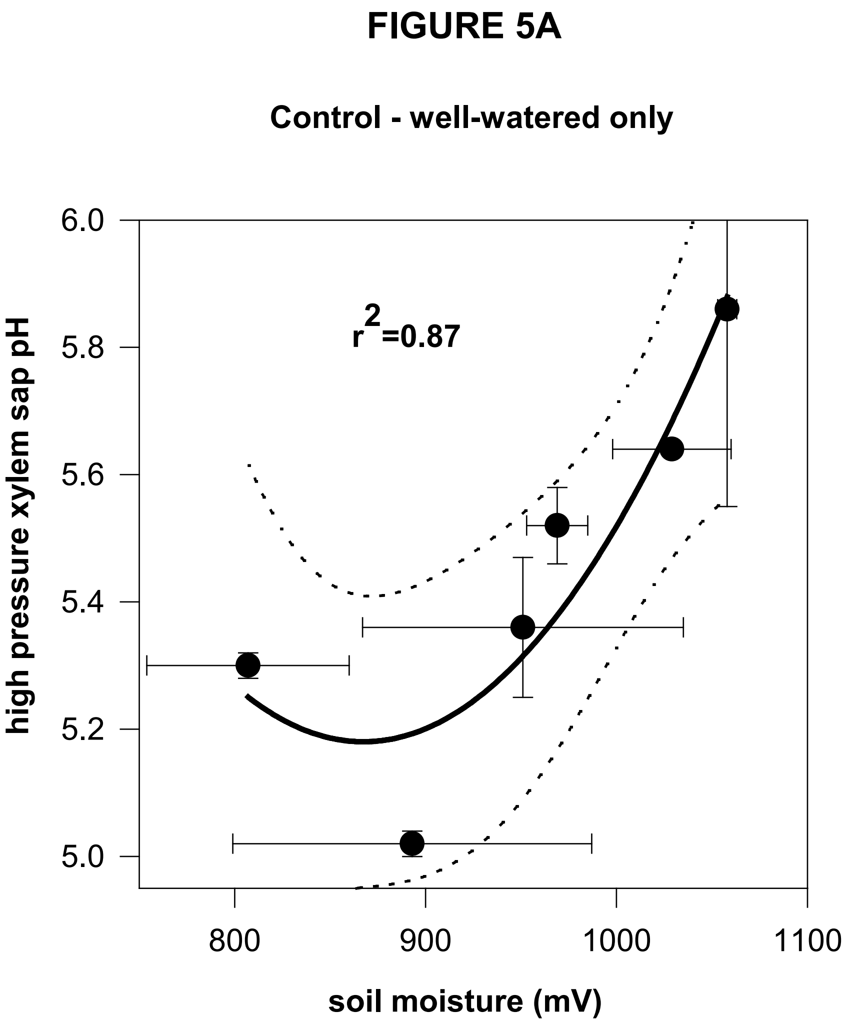


FIGURE 5A
Control - well-watered only
r2=0.87
high pressure xylem sap pH
6.0
5.8
5.6
5.4
5.2
5.0
800
900
1000
1100
soil moisture (mV)

Figure 3.5 B

FIGURE 5B

A+B - well-watered only

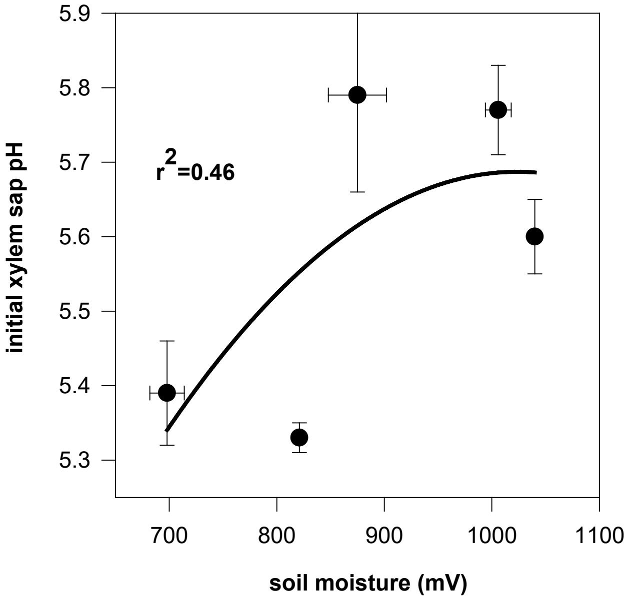
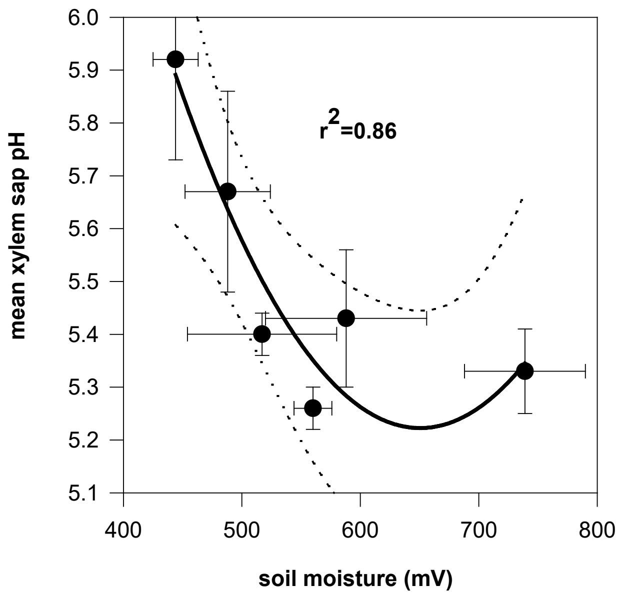


Figure 3.5 C

FIGURE 5C

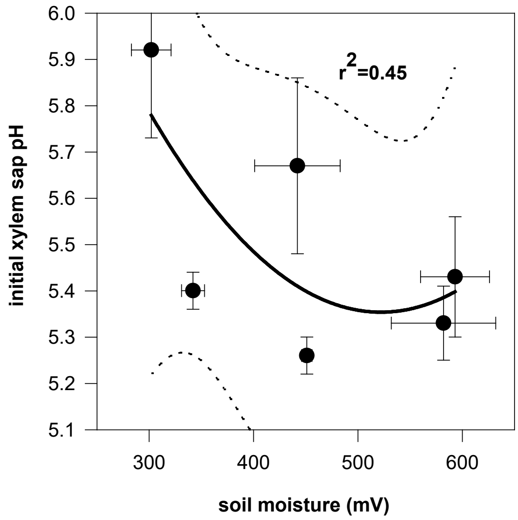
NH_4Cl RDI - dry soil only



<u>**Figure 3.5 D**</u>

FIGURE 5D

$KHCO_3$ RDI - dry soil only



<u>**Figure 3.6 A**</u>

FIGURE 6A

Control well-watered + RDI initial xylem pH vs leaf 3 gs

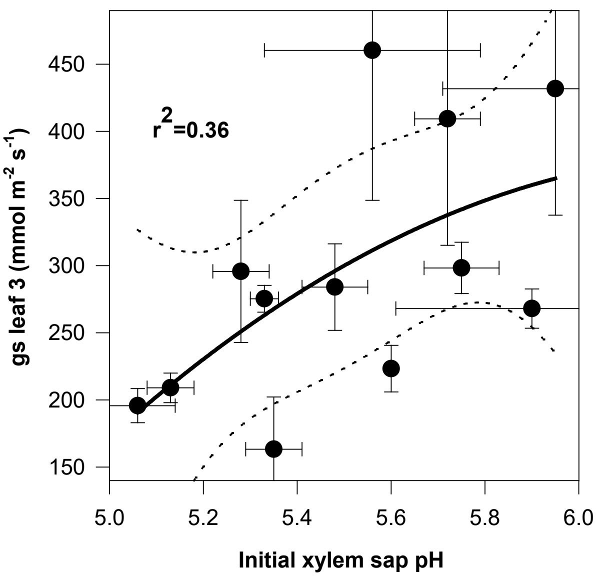
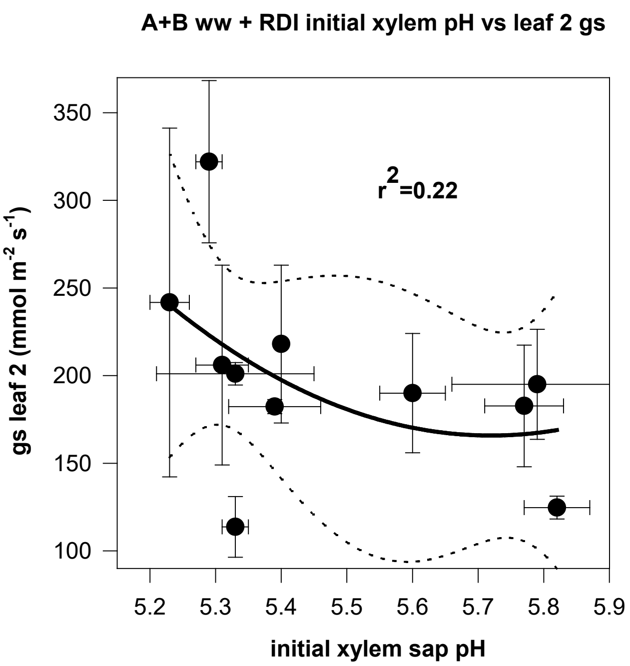


Figure 3.6 B

FIGURE 6B



Future work

1. It will be important to examine the effects of A (and B) alone on stomatal aperture in soil incipiently drying at the wetter end of the soil moisture spectrum, and to correlate any predicted reduction in stomatal aperture by A to either changes in xylem [ABA] or pH.

2. It would be interesting to test a greater variety of compounds that might be predicted to acidify xylem sap, on stomatal aperture in relatively wet soil. There are probably many more "water-saving" compounds in existence which are as yet untested.

3. Effects of nutrients on gs and growth in *Hydrangea* and *Cotinus* will be tested this year.

4. It may also be interesting to test the effects of nutrients on gs and growth in non-woody plants. Xylem sap pH is acidic in wet soil in these species, becoming more alkaline in dry soil - a confirmed signal for a reduction in growth and stomatal aperture. Since we have shown above that compounds A and B alone were able to increase xylem sap pH in dry soil, it may be possible for them to induce closed stomata and reductions in growth in non-woody species in wetter soil than normal. Preliminary work in tomato indicates that A, B and A+B all accentuate an effect of soil drying to alkalise xylem sap pH, and B and A+B sensitise stomatal closure to soil drying, ie. they improve water use efficiency. Effects on growth characteristics have not been tested.

DEVELOPMENT OF MANAGEMENT PROTOCOLS FOR OVERHEAD IRRIGATION.

OBJECTIVE 5

HRI EFFORD AND CENTRE FOR ECOLOGY AND HYDROLOGY

This report concentrates on the practical implementation and effects of the irrigation management regimes compared in 2001, and complements the report on equipment and instrumentation provided by CEH.

Objectives 2001

- Compare an irrigation schedule based on an Evaposensor estimation of ETp and hence irrigation need, with one based on pot weighing to estimate ETp.
- Gain initial experience with automatic irrigation scheduling based on direct in-pot measurement using a Theta probe linked to a solenoid via a controller.
- Evaluate the application of 100% and 50% ETp irrigation regimes in the open on the growth and quality of plants.
- Obtain further data on water use under different irrigation management systems.
- Demonstrate equipment and methodology, and present applied results to the industry through an Open Day.

These objectives relate to the milestones:

5.8 Develop management protocols for non-automated, overhead irrigation control. [31/12/01]
5.9 Present data on effectiveness of equipment to control overhead irrigation and demonstrate results to industry. [30/9/01]

Treatments

Irrigation management

A Irrigation to 100% of evapotranspirative demand of well watered plants (Etp) measured by weighing.

B Irrigation to 100% Etp as estimated by Evaposensor readings.

C Irrigation to 50% of Etp estimated by Evaposensor (i.e. 50% of treatment B applications).

D Automatic irrigation controlled by a single Theta probe in a representative container.

Species

Hydrangea macrophylla ‘Blue Wave’
Cotinus coggygria ‘Royal Purple’

Method

Liners were potted into 3.0 litre containers in early April (*Hydrangea*) and mid April (*Cotinus*). They were held under cold glass initially and then stood out on the outdoor beds in mid May. It was only possible to use single replicate main plots for irrigation treatments, but within these main plots, each species was replicated 3 times in sub-plots of 16 assessed plants/plot plus a surrounding border of guard plants.

Weighing was carried out daily on sample plants in all plots. Following results in 2000, where irrigation requirements were similar between species, irrigation to both species in the plot this year was determined by the estimated requirements of *Hydrangea* only. Irrigations were applied daily to treatments A-C during weekdays as required.

The application of treatments was undertaken in two parts. Up until the end of June, similar quantities of irrigation were applied to Treatments A, B and D representing an estimated 100% of ETp measured by weighing. 50% of this quantity was applied to Trt C. During this period, Evaposensor, water meter and gravimetric data were used to calibrate the system and derive a relationship between Evaposensor readings and ETp, and the amount of time irrigation needed to be applied to replace water loss. During this time, the hardware and software to apply Trt D was also installed and tested. From the start of July until the end of the experiment (late October), the Evaposensor and Theta probes were used to schedule irrigation in Trts B, C & D.

Results and Discussion

Distribution of irrigation

Improvements to the irrigation sprinkler system were made for this year's experiments. Eindor 862 Minicompact sprinklers were used to provide good uniformity of application rate over the plots. 9 sprinklers per plot were arranged in 3 lines of 3 at a 2.0 m x 3.5 m spacing. Windbreak netting was used to prevent overspill and interference between treatments.

Figs 5.1 & 5.2 show the results of a sprinkler calibration test using water collected in drip trays (without the presence of a crop), and also the uptake by the *Hydrangea* crop as measured by pot weight gain. The charts represent a cross section across three growing beds with irrigation sprinklers along the top, bottom and centre of the plot. Data was collected following a (heavy) 45 min. irrigation in mid October 2001.

- Fig 5.1 - Even distribution of irrigation as measured by the open containers was close to the design specification of 10 mm/h with a good coefficient of uniformity and low scheduling coefficient.
- Fig 5.2 – Effect of foliage of *Hydrangea* caused more variation with a poor Cu and SC. On average mean application rate was higher (13.5 mm/h) due to 'funneling' effect of foliage with some pots.
- Although water capture by the pots looked uneven from this single irrigation, repeated irrigations would even out the distribution pattern. This test would also not account for any redistributed overhead-applied water, that fell between containers onto the bed, which was taken up by capillary action through the base

of the pot. There was evidence that some water was being supplied this way from the mini-tensiometer data measured at three depths in the container (see CEH instrumentation report).

- The proportion of run-through on this occasion varied from 0-50% of the total quantity captured by the pot. There was some tendency for pots that were heavier (wetter) before irrigation, to have a greater proportion of drainage.

Fig 5.1

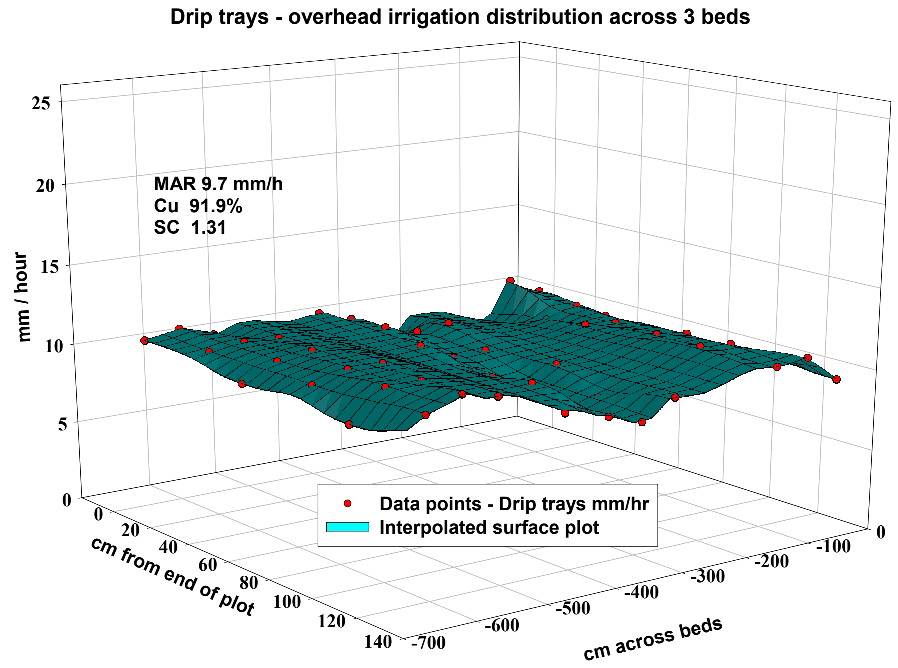
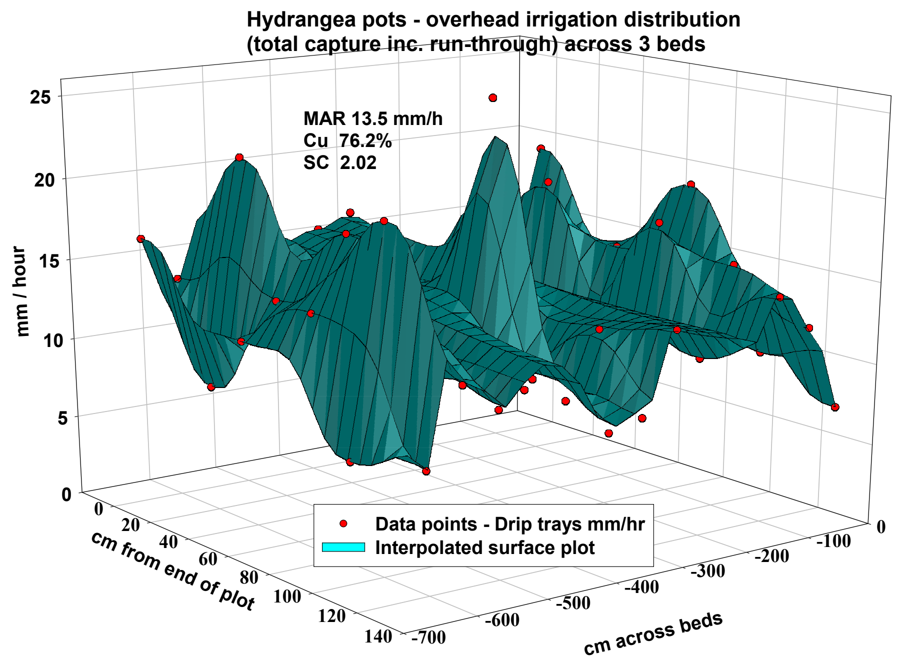


Fig 5.2



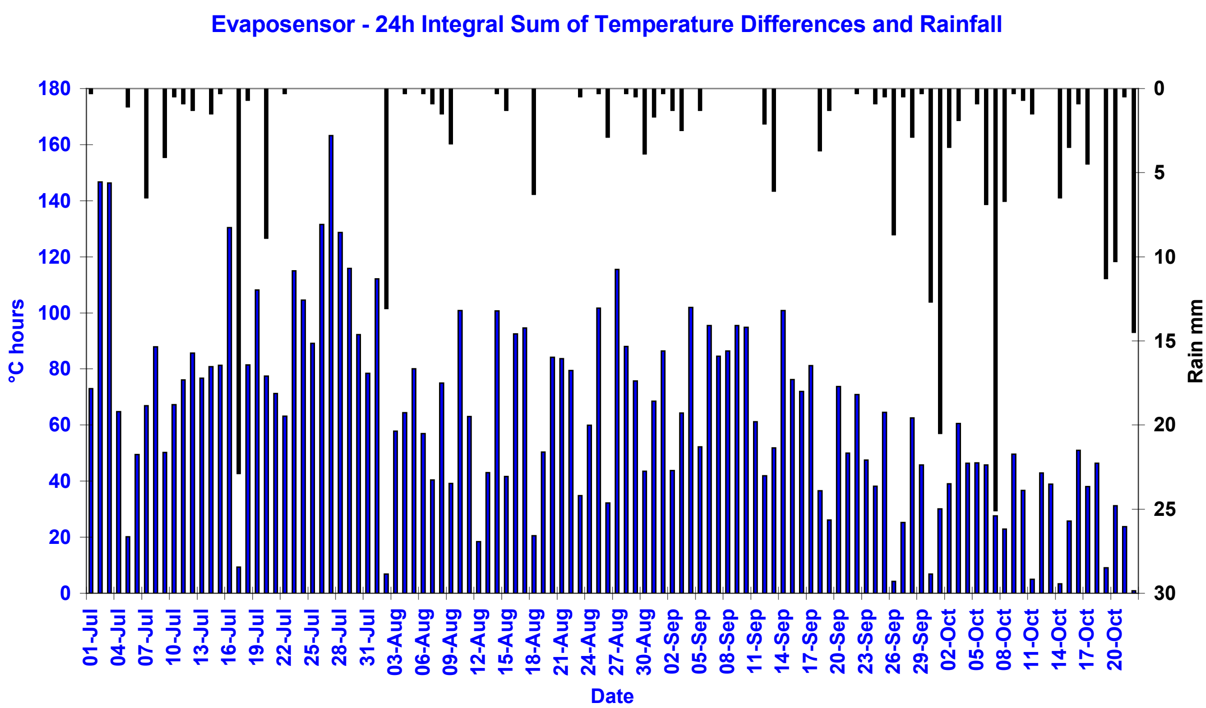
Effectiveness of irrigation management treatments

- The data collected in the first half of the season to calibrate the Evaposensor was successfully used to apply treatments from July onwards. This was achieved by correlating a number of 24 h Evaposensor readings to 24 h weight loss (mean of 6 plants). Then the mean weight gain of pots was correlated with litres irrigation per plot applied using suitable data from 16 irrigation occasions. Using the equations from best fit straight lines, a lookup table was derived to convert Evaposensor readings to quantities of irrigation required per plot. As the pressure and sprinkler output was reasonably stable, irrigation volumes could be readily converted into timer settings. In theory, this conversion would need adjusting as the crop developed, canopy density changed, and thus the efficiency of water capture by the container, and rate of loss from day to day changed. In practice, a single conversion table was found to be satisfactory for the period from July onwards in this experiment.

  In 2002, the process by which a nurseryman can simply calibrate the Evaposensor will be examined further.

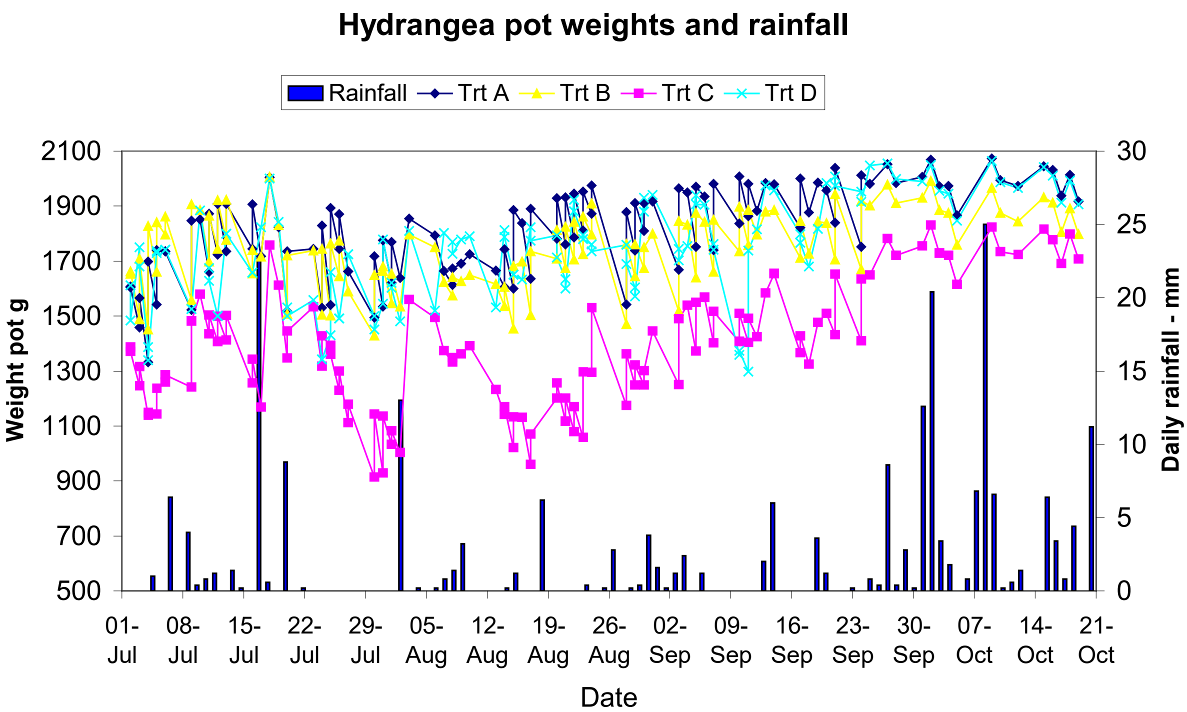
- Fig 5.3 illustrates the day to day fluctuation in Evaposensor values and the reduced ETp on rainy days. Also, how ETp generally reduced from late September into the autumn.
- Skye Instruments' Evapometer gave comparable readings to the Evaposensor plus DL3000 logger setup, was easy to use and appeared robust.

Fig 5.3



- The Evaposensor does not account for water gain by pots from rainfall. Strictly speaking, daily rainfall should be used to adjust the Evaposensor estimation of irrigation need. In practice during 2001, however, formal adjustment with rainfall records was not found to be necessary. Rainfall events from July to mid September were either too light or infrequent to make any significant difference, or obviously heavy enough to bring containers to pot capacity and irrigation was not applied.
- Mean *Hydrangea* pot weights (Fig 5.4) remained very similar for Treatments A, B and D which showed that the 100% ETp Evaposensor and automatic Thetaprobe controlled treatments were applying a similar irrigation regime on average to the Control treatment A irrigated according to pot weight. Treatment C pots, on the 50% ETp regime, were significantly lighter on average than in Treatments A, B & D, except where following high levels of rainfall.

Fig 5.4



- Occasionally, extra irrigation over the calculated amount, was required for Treatment C to prevent pots from drying out excessively and to prevent and recover wilted plants. This indicated that the plants did not fully 'down regulate' their water loss when irrigated to 50% of the ETp of the well watered ones.
- The results from using of a single Thetaprobe in a container to automatically control irrigation in Treatment D were extremely encouraging in this first year. Apart from one occasion when the DL-3000 logger malfunctioned over a weekend, no additional manually controlled irrigations, including any hand watering of edge plants by hose and rose, was required from early July when the treatment started, until the end of the season.
- Total water use for the automatic Treatment D was similar to Treatments A & B (Table 5.1), but larger quantities were applied less frequently, e.g. every 2 – 3

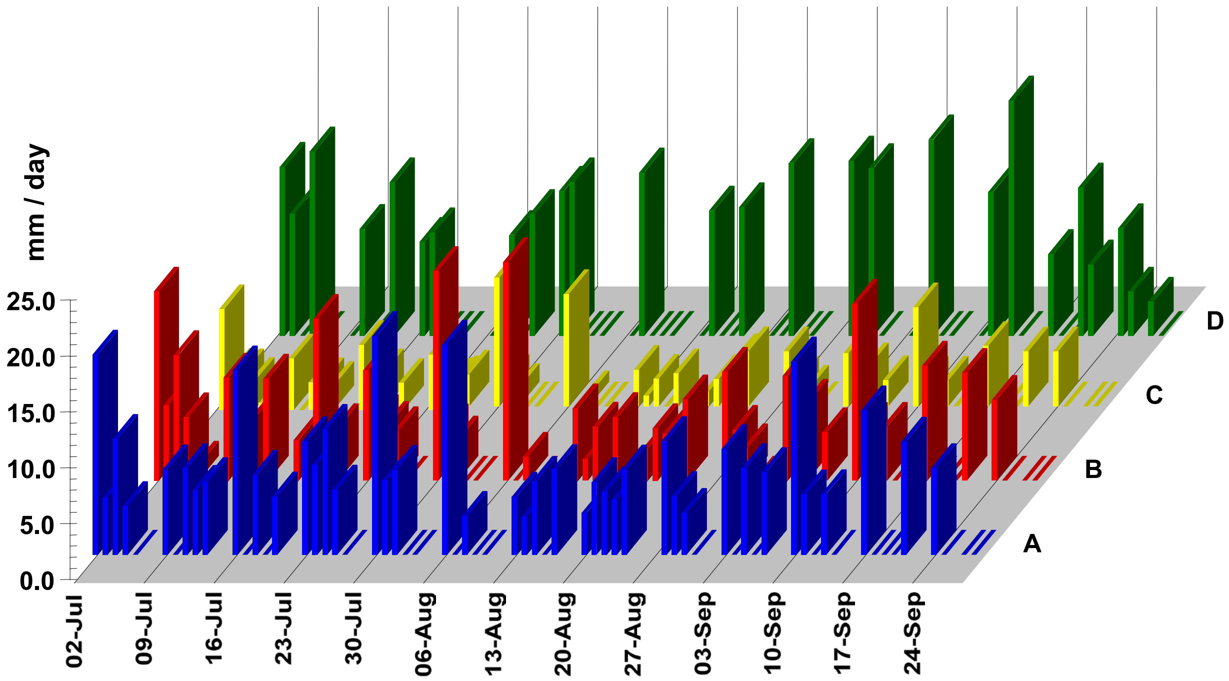
days in hot weather (Fig 5.5). It is possible that these more-but-less-often irrigations were also better at preventing plants in dryer parts of the bed from reaching wilting point, because the heavier irrigations would have penetrated deeper and wetted the growing media more thoroughly. Further work is needed to test whether little-and-often applications from an overhead system increase the tendency for plants in dryer areas to dry out to stress point.

- Overall water use was less than applied in 2000, probably because of the improvements in the sprinkler irrigation system, and the use of a wetting agent in the growing medium. Water use averaged 3.4 mm/day for the 100% ETp Treatments A, B and D between July and September. No irrigation was necessary from late September and during October.
- The 50% ETp Treatment C used about half the amount of water as the 100% Trt B.

Table 5.1

Mean mm/day	A	B	C	D	Rainfall
July	5.0	4.4	2.3	4.3	1.6
Aug	3.2	2.7	1.5	2.7	1.1
Sept	2.8	2.4	1.3	3.2	1.2
October	0	0	0	0	4.4
Jul-Sept	**3.7**	**3.2**	**1.7**	**3.4**	**1.3**
Jul-October	**2.8**	**2.4**	**1.3**	**2.5**	**2.1**

Fig 5.5 Pattern of irrigation applications for Treatments A - D during Jul - Sept 2001



Effect of irrigation treatments on plant growth and quality

Because the primary objective of this year's experiments at Efford was to test irrigation scheduling options rather than implement practical RDI regimes, it was decided to adopt a standard commercial pruning operation to all plants halfway through the growing season to maintain plant quality. *Hydrangea* were cut down by about half in mid July and *Cotinus* by end July.

- Treatment C did not exhibit the dramatic growth reductions shown at E Malling in previous years with individual pot dripper irrigation under protection. Nevertheless, by the end of the season, overall growth was less for both *Cotinus* and *Hydrangea* in Treatment C, reflecting East Malling's results that, in this season at least, it was possible to induce RDI effects outdoors despite occasional rainfall. The results from Treatment C also demonstrated that there was still potential for water saving with minimal loss of plant quality or growth by irrigating to less than 100% ETp.
- *Cotinus* plants received the same irrigation as the *Hydrangea* in the same plots. Despite being less leafy and generally smaller than *Hydrangea*, they often dried out more readily. It is possible that the reduced shading from the lighter foliage canopy in *Cotinus* was responsible for a significant water loss from the surface of the growing medium.

End of season growth and quality data is presented in Figs 5.6-5.9 below.

Fig 5.6

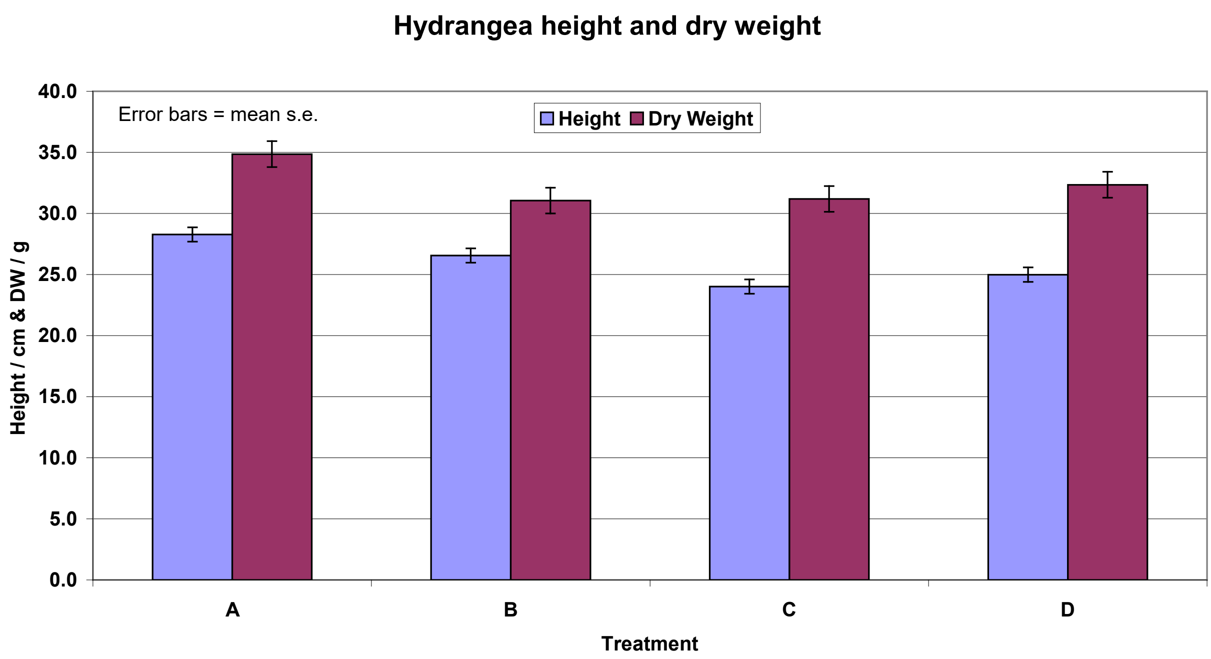


Fig 5.7

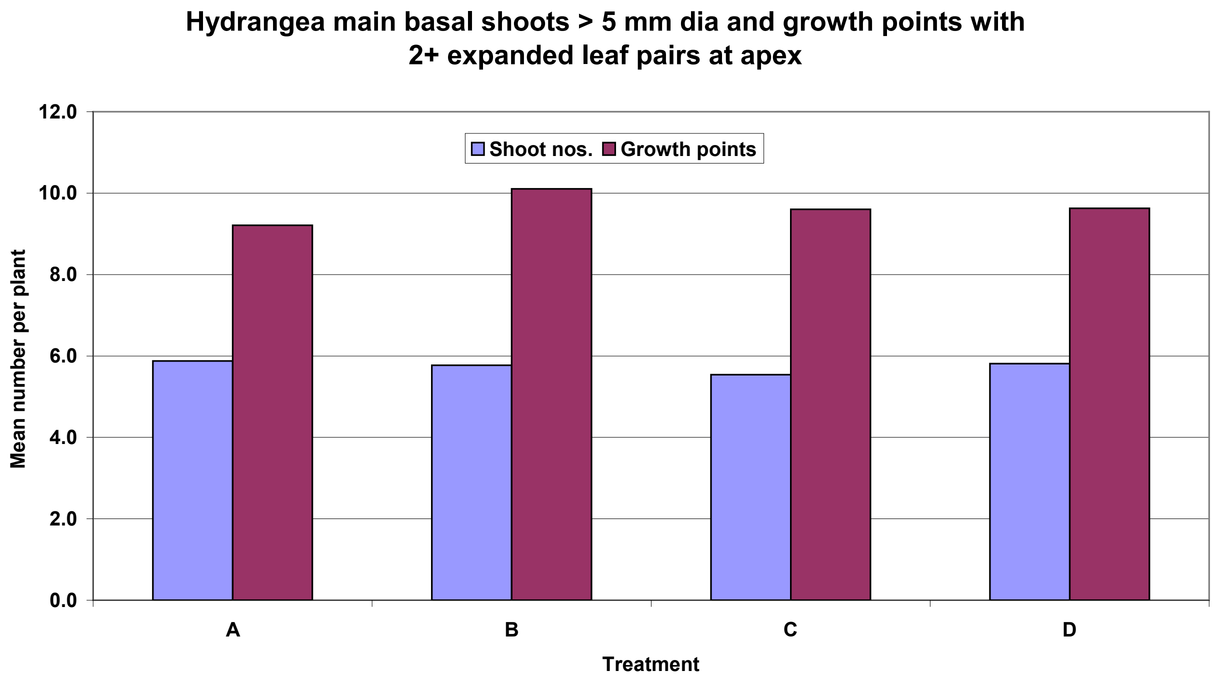

Hydrangea main basal shoots > 5 mm dia and growth points with 2+ expanded leaf pairs at apex
Shoot nos.
Growth points
Mean number per plant
12.0
10.0
8.0
6.0
4.0
2.0
0.0
A
B
C
D
Treatment

Fig 5.8

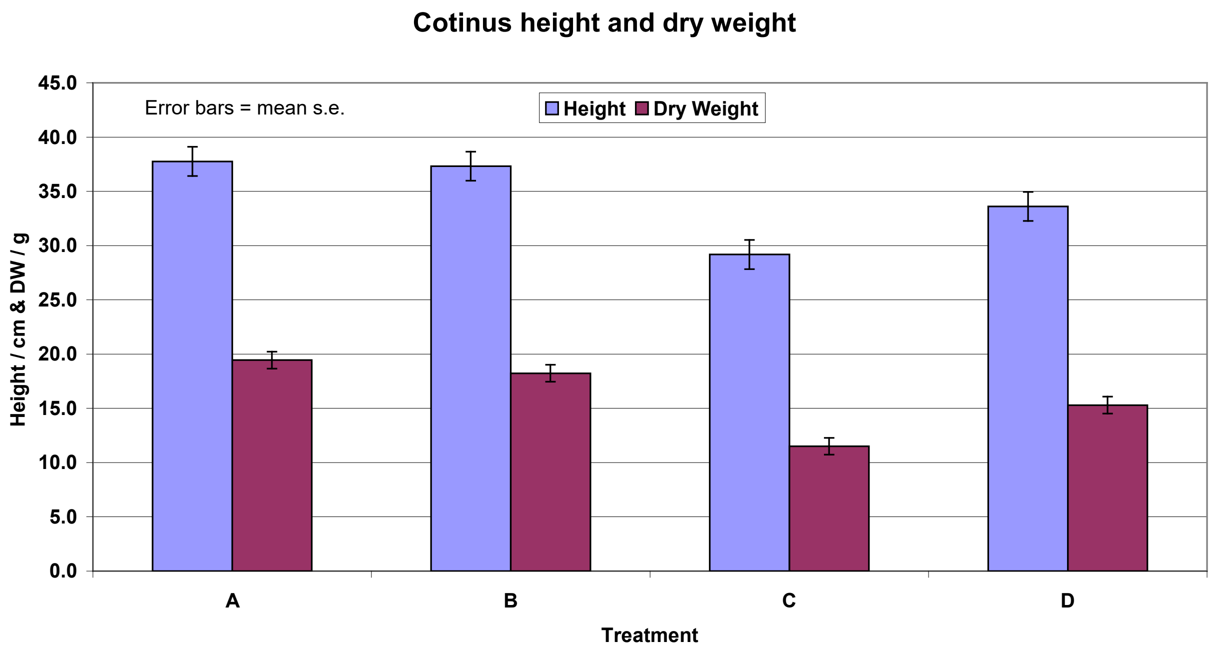
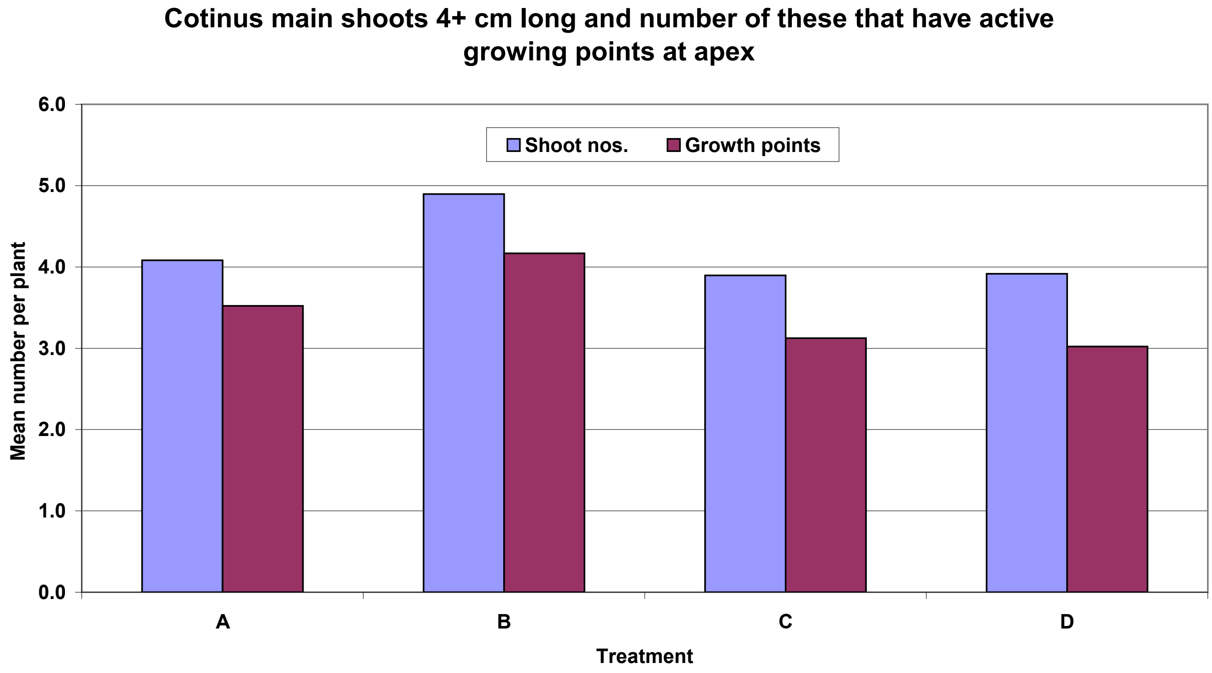

Cotinus height and dry weight
Error bars = mean s.e.
Height
Dry Weight
Height / cm & DW / g
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
A
B
C
D
Treatment

Fig 5.9



- The slight growth reduction due to Treatment C for both *Hydrangea* and *Cotinus* was reflected in height and dry weight rather than any clear evidence of differences in 'bushiness' expressed as numbers of shoots or active growing points.
- The pots of *Cotinus* under the automatic regime in Treatment D did run drier than the *Hydrangea* (see also CEH report), and this is reflected in slightly shorter and lighter plants in this treatment.

Conclusions and future work in 2002

The 2001 experiments firstly showed that achieving good uniformity of overhead irrigation is essential to underpin successful implementation of techniques to schedule and control irrigation in container nursery stock. Secondly, that both the scheduling approaches tried were feasible on a semi-commercial scale crop.

The Evapometer + Evaposensor method relied on estimating evapotranspiration losses from sensing the aerial environment, but using equipment that was considerably less expensive than a full weather station. This has the advantage that a single sensor can be used for a large number of cropping units on the same nursery provided they are in a similar environment (e.g. outdoors). The calibration of the output into actual irrigation requirements, however, would need to be adjusted for different beds according to irrigation systems used, plant and container size etc. This method also doesn't account for any water contribution from rainfall. However, as tool to help manage the day to day fluctuations in irrigation requirements due to the weather, it has considerable potential.

The automatic irrigation control using a Theta probe was a closed-loop feedback system, and so took all the complex factors affecting water capture and loss into account. Clearly, however, this requires the sensor pot to be adequately representative of the rest of the crop, which would limit the range of pot sizes, batches of plants at different growth stages etc. that could be controlled by a single sensor. Costs of sensors and controllers would be an important consideration in adopting this system, but it potentially offers the most precise method of control with the greatest saving in labour.

Proposed areas of investigation for the final project year are as follows:

- The Evaposensor and Theta probe scheduling methods should both be examined again using overhead irrigation but with crops standing on a capillary sand bed vs. gravel bed base. This will enable us to determine how important the type of standing base is to achieving the necessary uniformity of distribution to implement these scheduling options.
- Testing a prototype electronic 'black box' controller between the Theta probe and solenoid valve as more commercially viable alternative to the DL-3000 logger unit used in 2001.
- 'Calibration' of some overhead irrigation systems on commercial nurseries for output rate and uniformity.
- A first evaluation of Evapometers and / or Theta probe control systems on a commercial nursery.

SELECTION OF SENSORS FOR CONTROLLING THE IRRIGATION OF HARDY NURSERY STOCK

OBJECTIVE 6

CENTRE FOR ECOLOGY AND HYDROLOGY and HRI-EFFORD

Introduction

The two main objectives of the 2001 field measurements were to:

- further develop the management protocols for non-automated irrigation control
- develop prototype equipment to control and regulate irrigation automatically

These related directly to the following project milestones for this period:

5.7 Refine equipment as tools to estimate evaporative demand [31/7/01]

6.2 Develop appropriate interface and software for a data logger and sensors, such that they could act as a prototype automatic irrigation controller. [30/9/01]

Studies carried out during the 2000 season identified approaches based on sensors which fell into two main categories:

1. those that measure in the atmosphere. These allow the plant water use to be *estimated*. The water status of the growing medium can only be *inferred.*
2. those that measure in the growing medium, i.e. *directly* indicating the conditions of water availability to which the plant is subjected

The two types of sensors lead to two separate approaches to irrigation control which may be appropriate for different nursery situations.

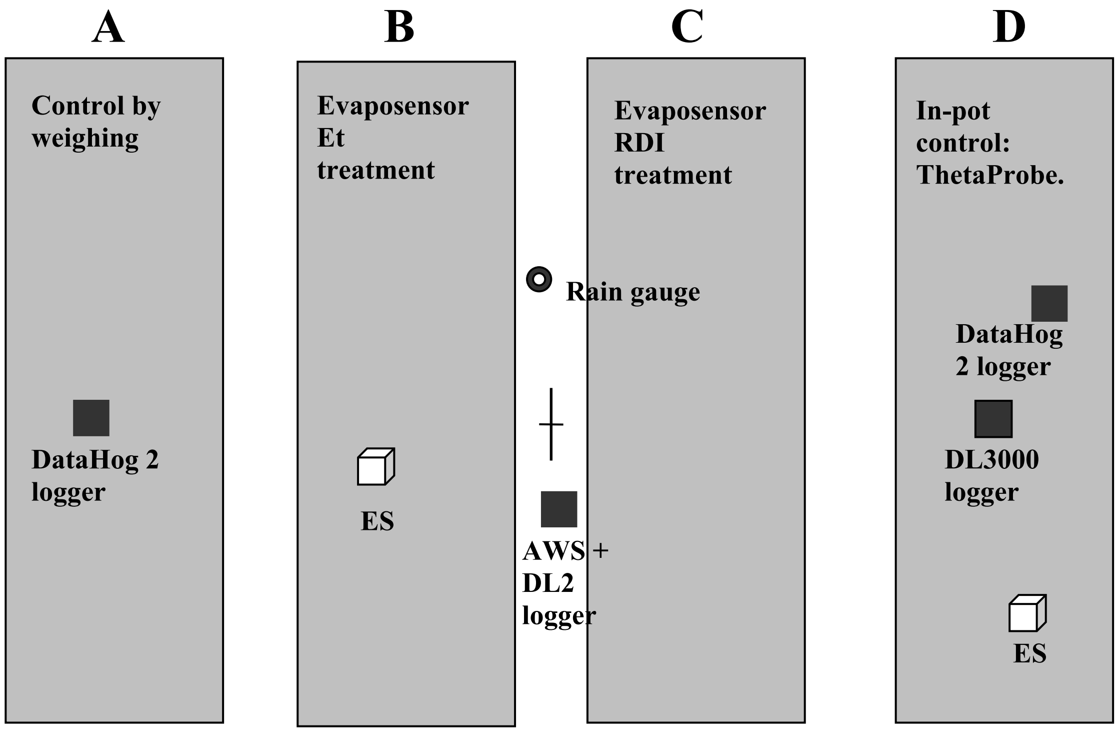
The estimation of evaporative demand with the evaposensor provides a low cost approach, but with a moderate to good ability to predict plant water use. There may also be a need for additional operator inputs to optimise irrigation for each bed. Rainfall should be measured and accounted for.

The *insitu* sensor approach does not require corrections for plant size, and rainfall need not be measured. There are fewer margins for error, and it lends itself to fully automated control on a bed by bed basis. Ideally, at least one sensor would be required per bed, which makes it a much more expensive option. The issue of spatial variability between pots must also be addressed. It was recommended that the in situ sensor approach would be best used with an irrigation system that provides more uniform application rates than most sprinkler systems in current use.

2001 Field Trial at HRI Efford

This should be read in conjunction with Objective 5 undertaken by HRI Efford which explains in more detail the design and daily operational procedures for the 4 irrigation control plots which were used. Emphasis is given here to the use and results of data-logged instruments. The location of automatically recording equipment within the four replicate plots is shown in Figure 6.1.

Figure 6.1. Instrumentation of Replicate plots at Efford, 2001



Tensiometers at 3 depths in 1 Hydrangea and 2 Cotinus pots. **Theta Probes** in 4 Hydrangea and 2 Cotinus pots	**Evaposensor** - data logger and portable **Theta Probes** in 4 Hydrangea and 2 Cotinus pots	**Auto. Weather Stn. + Rain gauge** **Theta Probes** in 4 Hydrangea and 2 Cotinus pots	**Tensiometers** at 3 depths in 1 Hydrangea and 2 Cotinus pots **Theta Probes** in 3 Hydrangea and 3 Cotinus pots **Evaposensor** on data logger

1. Skye Instruments, Evaposensor

This was used in 3 ways during the 2001 growing season.
During May and June, daily cumulative differences between the wet and dry sensor plates were calculated from hourly values (sub-sampled at 10 minute intervals) recorded on the AWS DL2 logger. This necessitated daily downloading of the data and manual calculation of the daily totals by HRI staff which was a time-consuming exercise.

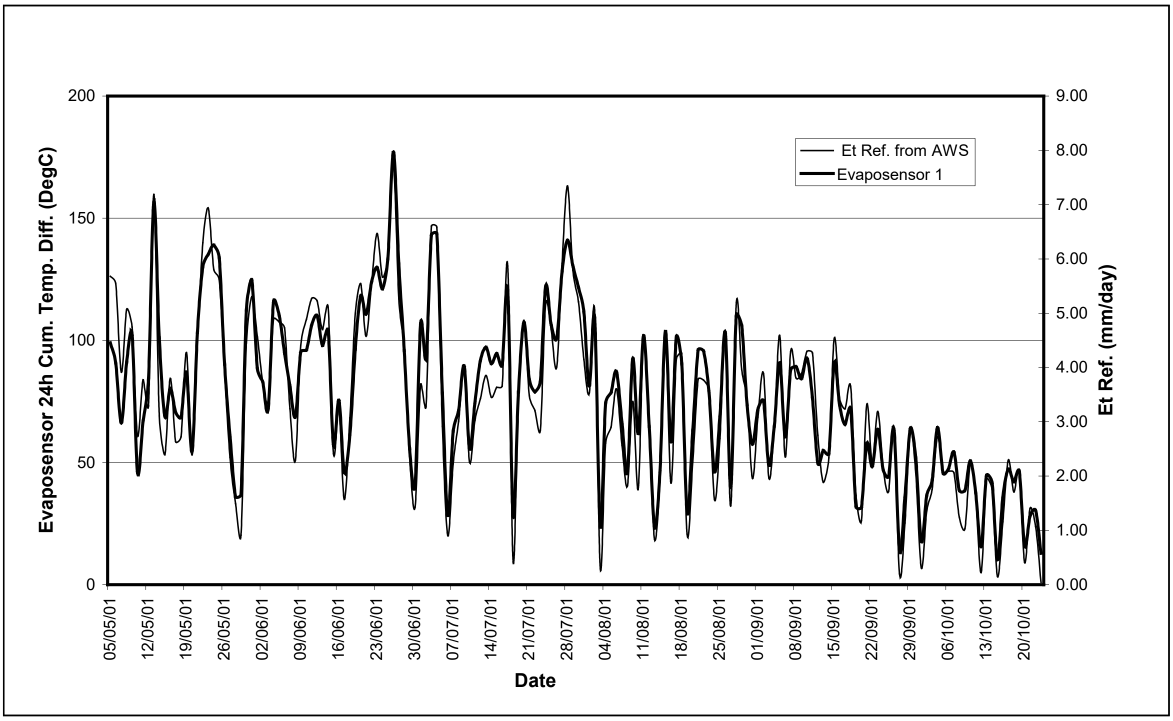
- By July, daily cumulative totals were calculated automatically using the programmable Delta-T DL3000 data logger which provided a digital display on interrogation. This produced a considerable saving in operator time.
- By August, Skye Instruments had produced a prototype hand-held integrator (the Helios Evapometer) which could be readily interrogated at any time of day to obtain a number of cumulative values e.g. value since last reading, last 24 hour value, last hourly value. This was simple and quick to use and became the preferred instrument for the remaining part of the season for calculating daily irrigation requirements, whilst the two original sensors continued to provide hourly values to the data loggers.

2. Automatic Weather Station and Skye Instruments Evaposensor

The AWS provided the standard meteorological reference measurements at hourly intervals against which the other measurements could be compared, as described fully in Annual Report 2. Daily rainfall was an essential component of the AWS record as this was required for the control of Plots B and C which was based on daily Evaposensor values.

A daily Penman-based reference crop evaporation (Et_{ref}) was calculated using the AWS sensors as an indicator of the evaporative demand of the atmosphere on the crop. Figure 6.2 compares Et_{ref} with the daily cumulative temperature difference between the wet and dry plates of Evaposensor 1 (treatment B)

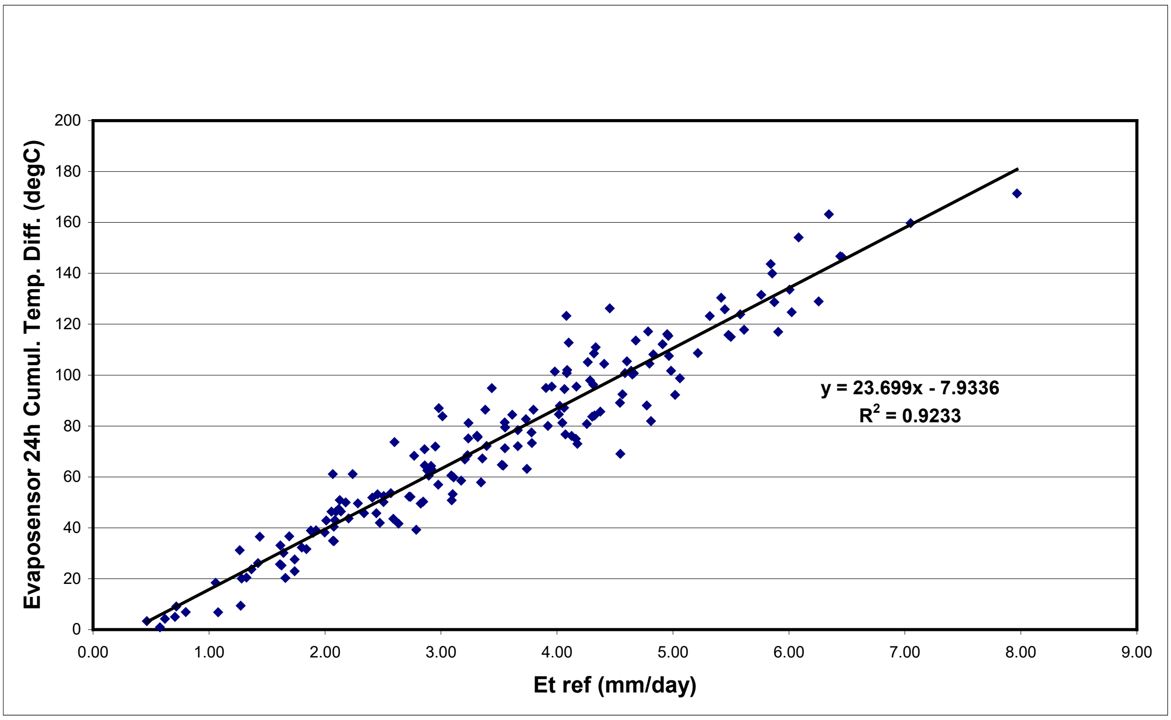
Figure 6.2. Comparison of Evaposensor 1 and ET_{ref} from automatic weather station



The data support last years results in the close correspondence again recorded between the two measurements in which seasonal trends are apparent. This is further demonstrated in Figure 6.3 where a high correlation between the two measures of evaporation is found (R^2 = 0.9233). For Evaposensor 2 (treatment D) the corresponding R^2 value was 0.9258. Comparison of the daily cumulative totals recorded between the Evaposensors sited on treatments B and D also return a high correlation coefficient (R^2 = 0.9353) indicating that there were only minor combined differences between instruments and sites.

These data further confirm the capability of the Evaposensor for providing a useful daily measure of evaporative demand which can be used (with care) to estimate irrigation requirement.

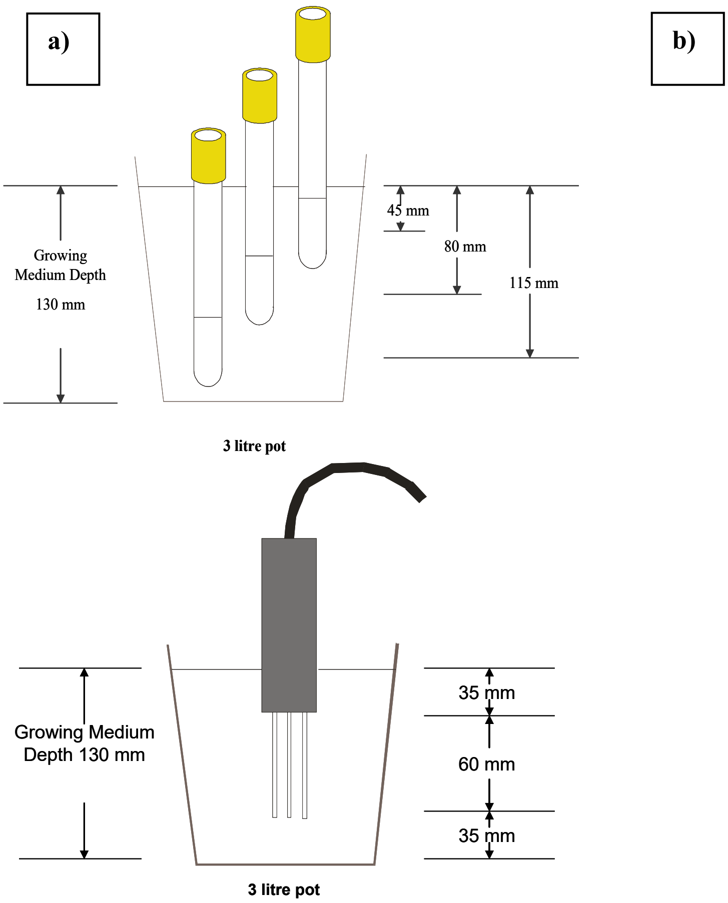
Figure 6.3. Relationship between Evaposensor 1 (Treatment B) and Et_{ref} for 2001 season



3. Delta-T Devices, ThetaProbe

This instrument provides an integrated measure of soil dielectric (and hence soil moisture via calibration) over a 6cm depth of growing medium. This was felt to provide a more representative measure of soil condition within the 12-13cm growing medium depth of a 3 litre pot than would be obtained using the <2.5cm length porous pot of the Skye Mini-tensiometer and was chosen as the preferred sensor to automatically control irrigation over Plot D. The small size of the latter was however used to advantage by providing measurements at 3 depths within a single pot as described in Section 4 and shown in Figure 6.4. ThetaProbes were buried to a depth of 3cm to reduce surface effects and to place the probes in the centre of the growing medium.

Figure 6.4 Location within 3 litre pots of a) Skye Mini-Tensiometers and b) Delta-T ThetaProbes



In each of the 4 treatments, 6 ThetaProbes were deployed to provide a measure of spatial variability within the *Hydrangea* and *Cotinus* plots where hourly readings provided good discrimination of diurnal, rainfall and irrigation events. In Plot D, the DL3000 logger provided the opportunity of selecting a number of sampling options from the available 6 ThetaProbes. After consideration of the future commercial/cost implications, it was decided to control the irrigation from only a single probe as this would be a more representative test of the 'real-world' situation. Data from year 2000 were used to select the initial 'dry' and 'wet' thresholds for irrigation switching (in Treatment D, *Hydrangea*, Plot 16, pot 5). Irrigation was switched on at a ThetaProbe reading of 500mV which corresponds to a soil moisture volume of 0.28 and off at 850mV (smv 0.45). The measurement time interval for the ThetaProbe which controlled irrigation was set at 1 minute to ensure that irrigation ceased as quickly as practicable once the upper threshold had been reached and the precision with which this was accomplished is demonstrated in Fig. 6.5. The horizontal parts of the stepped graph correspond to overnight periods when there was little change in pot moisture. It can be seen that in July, irrigation was required every 2-3 days, generally for a period of between 60 and 90 minutes, which corresponded to a sprinkler application of around 10-15mm. In Figure 6.5, deviations above the 500 and 850mV lines correspond to rainfall events.

Figure 6.5 In-pot soil moisture variation recorded by the ThetaProbe which triggered irrigation: Treatment D, Hydrangea, pot 5

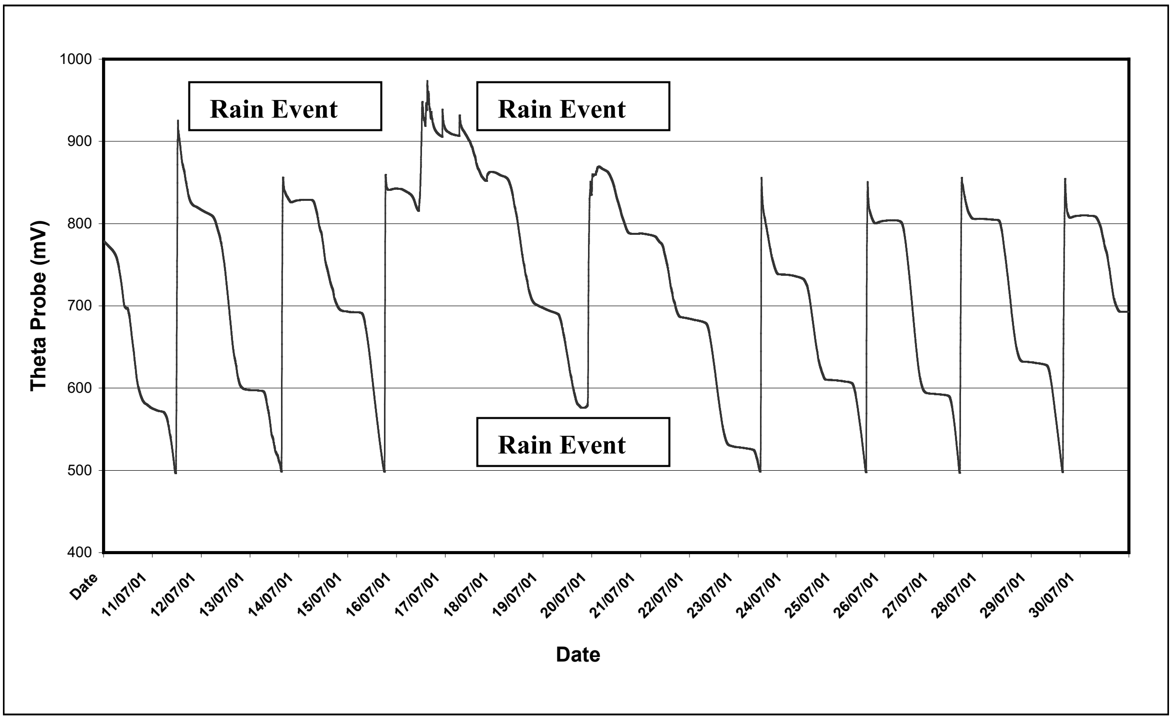
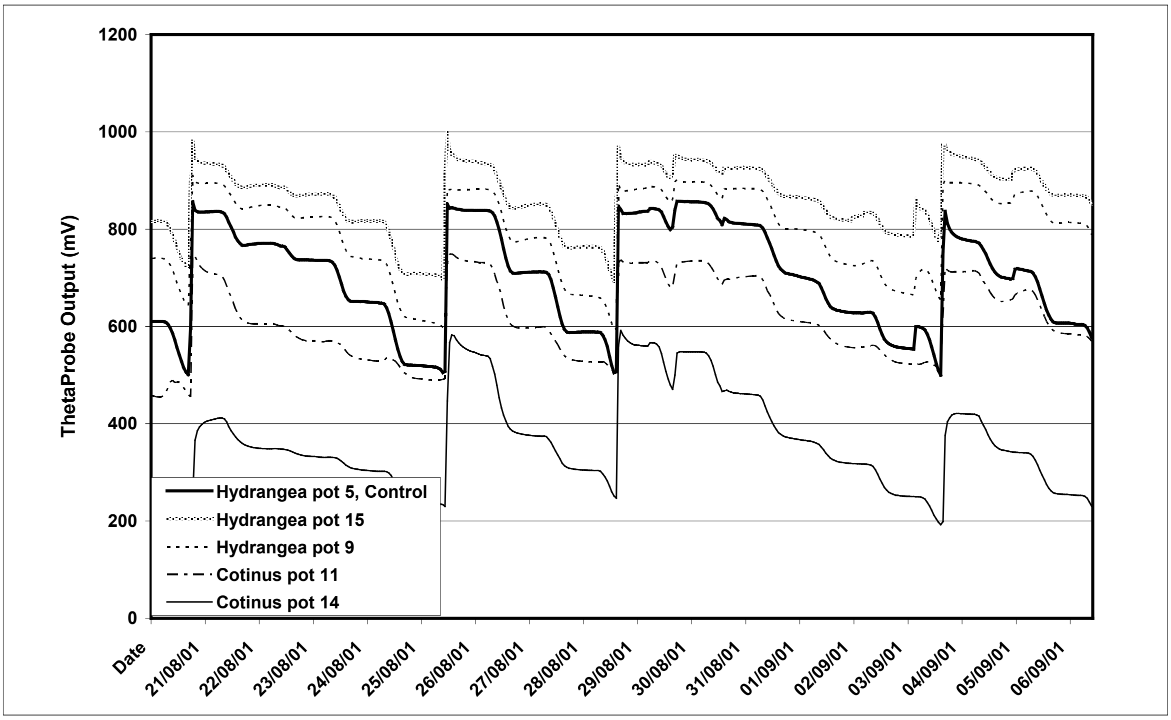


Figure 6.6 Variability of in-pot moisture in Treatment D as sampled by ThetaProbe



For the irrigation of a large bed to be successfully controlled my measurements made in a single pot, the selected pot should be reasonably representative of the whole bed. In general, it has been found that pots retain their relative moisture ranges throughout the growing season, probably as a combined result of initial potting medium state, location in relation to overhead spray nozzles and vegetation canopy effects. In other words, wetter pots stay wet and drier pots stay dry, so the objective would be to select a pot near the middle of this range. Ideally this could be determined by weighing or by use of a portable soil moisture probe, or if this is not possible, by hand weighing and observation of the moisture state of the medium. In Figure 6.6, the pot selected for irrigation control lies at the drier end of the *Hydrangea* moisture range, but is wetter than the *Cotinus*. This resulted in *Cotinus* being subjected to a drier watering regime for the whole growing season and was effectively a form of RDI. As a consequence, the *Cotinus* appeared to adjust to the RDI and showed no detrimental signs.

4. Skye Instruments, Mini-Tensiometers

Mini-tensiometers were set at 3 depths (4.5cm, 8.0cm and 11.5cm) within individual pots to gain a better understanding of water distribution and movement during irrigation and drying cycles and recorded at hourly intervals. Some seasonal changes could be seen which were probably associated with changes in canopy and root development. Figure 6.7 is for the same treatment and time period as Figure 6.5. The near surface layers can be seen to dry more rapidly than the middle and lower layers after each application of irrigation and this is typical for both the *Hydrangea* and *Cotinus* when plant water requirements are being met. However, at times of water shortage when irrigation fails to meet the demand, the situation changes as shown in Figure 6.8. Whilst the supplied irrigation is continuing to keep the top and bottom of the pot reasonably moist, it is insufficient to stop the centre of the pot from drying out as a result of the dense root structure in this region. The bottom of the pot also starts to dry out slightly faster than the top, presumably because it is only supplied through capillary rise during and after irrigation, and also because root density is higher than in the near surface layer.

Figure 6.7 Mini-Tensiometers at 3 depths, Hydrangea Treatment D, Pot 2, during a period of normal irrigation

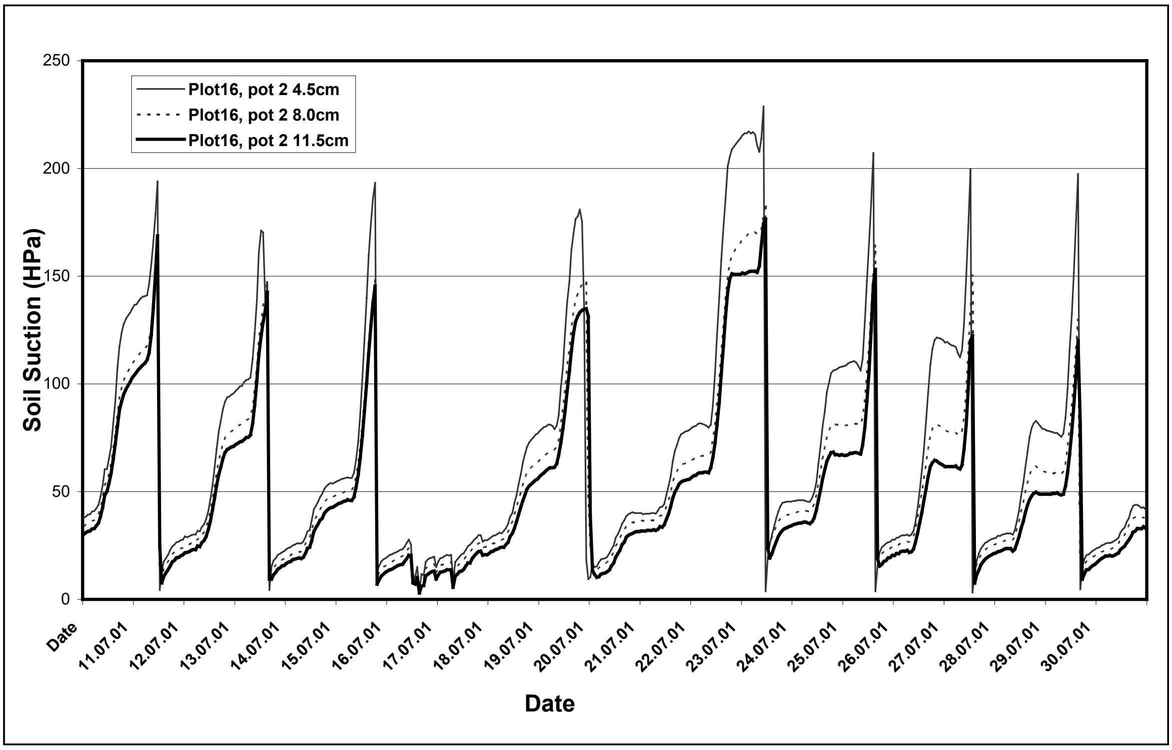
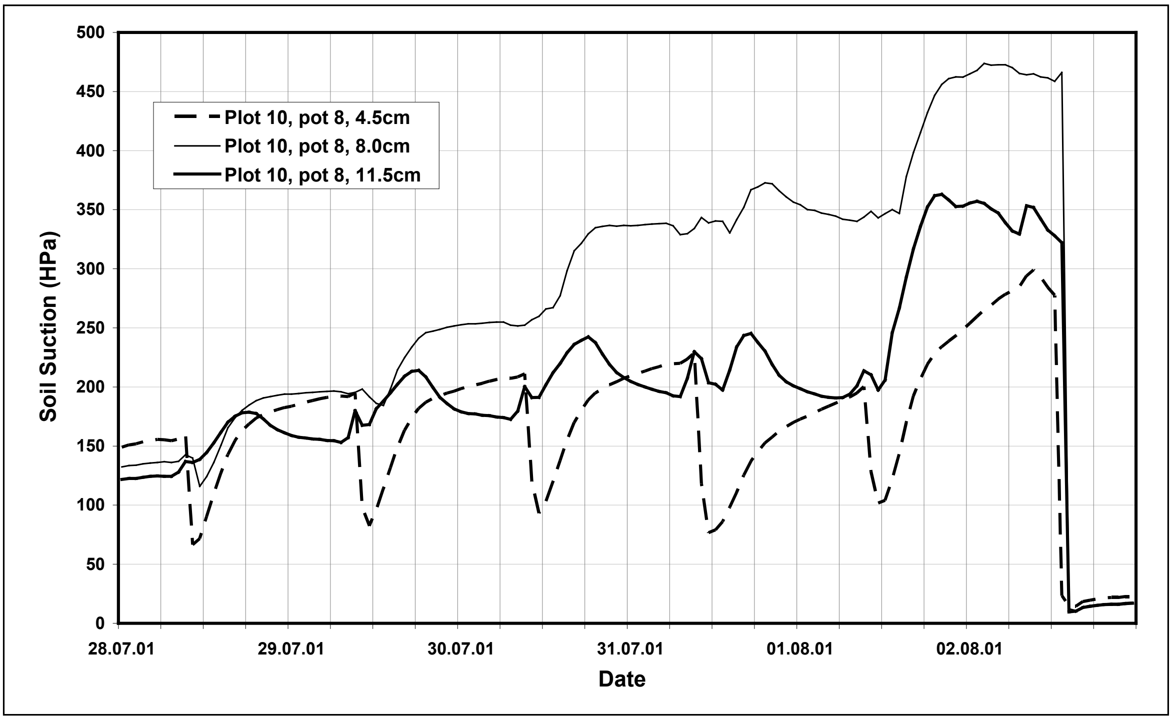


Figure 6.8 Mini-Tensiometer traces in Hydrangea, Treatment A during a period of water shortage



The evidence for capillary wetting of the lower layers lies in the timing of the peaks and troughs found in the trace from the 11.5 cm depth tensiometer. The time of daily irrigation is clearly depicted by the sharp fall in the 4.5 cm data (dotted line). Immediately prior to irrigation, the 11.0cm trace is rising as a result of an early morning increase in water demand. This is reversed only slightly for 1-3 hours after irrigation, after which, it continues to rise to a peak at around 18.00 GMT. Whilst the surface layers continue to dry slightly overnight, the soil suction in the bottom layer drops quite markedly up to midnight and then less slowly for the rest of the night. This suggests that some water replenishment of the bottom layer is being supplied by capillary action from the semi-permeable mypex covered sand bed during hours of darkness. This is in addition to the periods of irrigation when some water can be expected to be drawn directly from the surface of the mypex.

Whilst it is currently difficult to quantify the proportion of water entering the pot from the base, this will be further investigated during the 2002 season by having a control on a permeable gravel base to minimise this effect.

5. Conclusions from 2001 Measurement Programme

- Automatic irrigation control using a single ThetaProbe was very successful and resulted in no plant losses in either *Hydrangea* or *Cotinus* plots.
- ThetaProbe control in *Hydrangea* effectively produced a reduced deficit irrigation regime in *Cotinus*, but no detrimental effects were evident.
- Evaposensor daily integrated totals were calculated automatically, demonstrating that this could be potentially developed for automatic control of irrigation
- A low-cost, manually-read Evapometer provided a simple route for the manual estimation of irrigation needs on a variable time scale if required.
- Mini-tensiometer results confirmed that the middle segment of the pot is the most suitable location for sensors controlling irrigation as this is the first to dry during periods of high demand.
- The pot selected for irrigation control should lie in the middle to dry end of the moisture distribution for a given bed.
- Further investigations are required to determine the importance of irrigation redistribution resulting from different bed types.

DEVELOPMENT OF AN ECONOMIC MODEL

OBJECTIVE 8

HORTLINK PROJECT - WRc PROGRESS REPORT FEBRUARY 2002

Nursery data collection

Detailed water use records were received from three nurseries for the 2001 growing season (Johnsons, Wyevale and Notcutts). Each nursery recorded its water use on a covered and an outdoor bed together with information on weather conditions, including temperature and rainfall. The paper based records were transferred onto Excell spreadsheets to allow for further analysis.

The analysis was carried out and reported in a short report issued in January 2002, (Summary of Nursery Water Use 2001, WRc report no UC4030 – See next section).

Instrument specification

As previously agreed, the instrument specification will not be progressed further until a clearer picture of its requirements are known. Hence, no further work has been done in this area during the past 6 months.

Economic model

The comments made at the November 2001 consortium meeting have been considered by WRc. The consortium suggested that the current draft of the economic model should be simplified further from the versions already presented.

In response to the wishes of the consortium a further draft of the model will be produced. This will not be a full cost-benefit model of any water conservation strategy, as was envisaged in the original project proposal, but will focus closely on water use and savings only.

In light of the limited remaining budget for this item, it is important that the requirements of the consortium are clarified before further model development. WRc are contacting the growers within the consortium to define:

- The format of the model outputs required (who will use the model and what for, what about other stakeholders, e.g. regulators);
- The scope of the model (what cost-benefits to exclude; whether to implement on a crop level or nursery level, etc.)
- The format of water-use/savings data that has been generated by the partners (required to populate the model).

This information is currently being pursued and once the revised requirements are clear, WRc will re-draft the tool and forward it to consortium members for comment.

The due date for delivery of the model is end September 2002.

Literature review

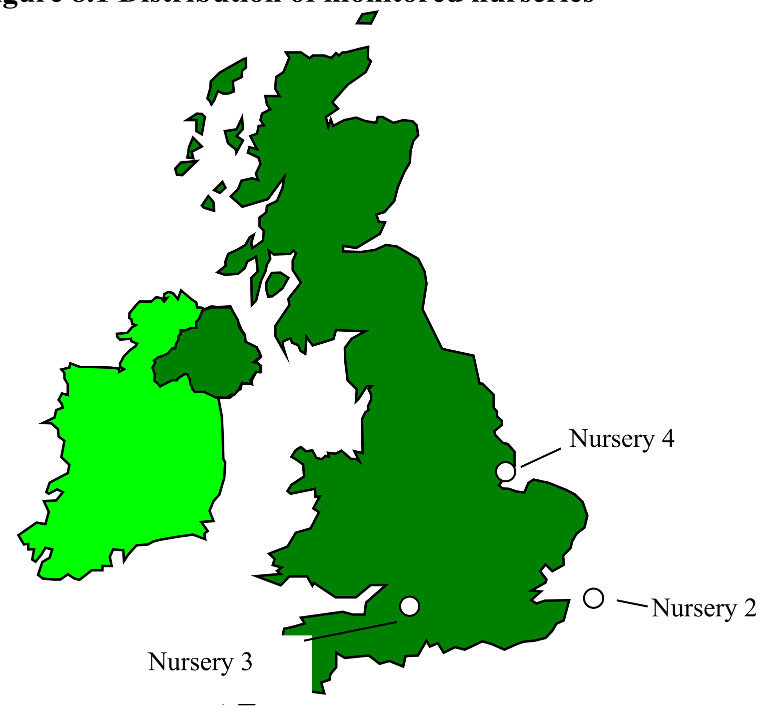
A web based search has thrown up a significant number of new articles and patents on irrigation control. Many of these are connected with the control systems and/or communications between field based sensors and control systems. References have been found to the use of technologies such as GSM (mobile 'phones), two wire communications, neural networks and internet based systems for communications and control. In terms of the sensors used for control, various articles have been located on work being undertaken on soil moisture content (tensiometers). Fewer references have been found on the use of transpiration. These latter have included methods which look at the physical characteristics of the plant, e.g. leaf temperature or thickness, and weather data, e.g. maximum and minimum temperatures. This information is currently being collated and written up.

SUMMARY OF NURSERY WATER USE 2001

Introduction

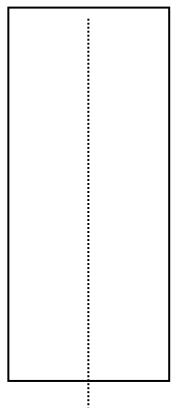
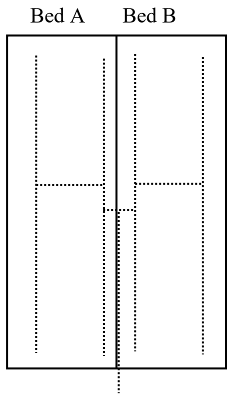
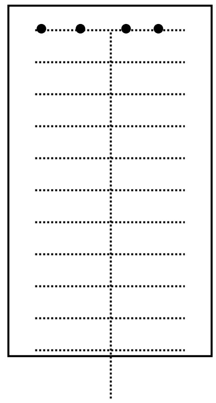
As part of its contribution to the Link Project HL0132LHN Improving the Control and Efficiency of Water Use in Container Nursery Stock Production, WRc were asked to monitor water use in a number of nurseries. This was carried out over the 2000 and 2001 growing seasons. Data from the 2000 season has already been reported; this report summarises nursery water use for the 2001 growing season. Water use was monitored in detail at three nurseries in different areas of the country, see Figure 8.1. The reference numbers used in this report are consistent with those in the previous report. A fourth nursery (nursery 1) which supplied data in 2000 did not keep detailed records in 2001. On each nursery the irrigation to one outdoor bed and one covered bed was measured on a daily basis. Records of daily rainfall and weather conditions were also kept.

Figure 8.1 Distribution of monitored nurseries



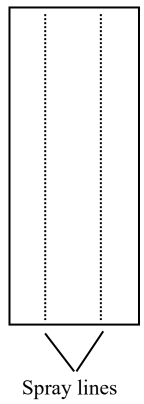
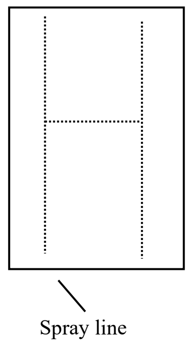
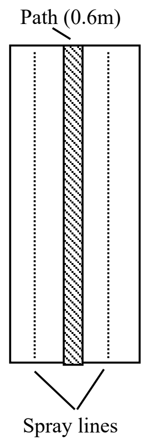
Bed details

<u>Outdoor beds</u>

	Nursery 2	**Nursery 3**	**Nursery 4**
Total area	1313m^2	2 x 440m^2	1014.6m^2
Layout	13 x 101m  Spray line	2 x 8 x 55m (see note)  Spray lines with 4 lines of 7 nozzles	17.8 x 57m  Spray line with 11 rows of 4 nozzles
Number of nozzles	11 in 1 central line	28 in 4 lines of 7 all firing in 180° arc	44 in 11 rows of 4
Distribution radius	22.8m	8m	5.65m
% water lost	63%	<1%	16%
Bed	10/20mm gravel on Mypex	Data not supplied	Gravel
Crops	Mainly Berberis, some currants, gooseberries and Physocarpus at various points in the season	Bed A Corylus Bed B Rose	Data not supplied
Data collected	1 April – 25 Oct	9 Apr – 30 Sept	1 Apr – 13 Nov
Irrigation period	5 May – 14 Oct	A 29 Apr – 30 Sept B 21 May – 30 Sept	11 May – 18 Sept

Note: The outdoor bed of nursery 3 comprised two beds which were irrigated from a common supply but controlled independently. The nature of the site meant that the water meter had to be fitted prior to the split between beds. The timing of the irrigation to each bed was recorded and the total volume recorded was allocated across the beds in the ratio of the timings.

Covered beds

	Nursery 2	**Nursery 3**	**Nursery 4**
Total area	259.6m^2	600m^2	222m^2
Layout	5.9 x 44m 	12 x 50m 	6.3 x 35.25m 
Number of nozzles	60 in 2 lines of 30	20 in 2 lines of 10	48 in 2 lines of 24
Distribution radius	5.8m	6m	1m
% water lost	35%a	0	0
Bed	Mypex on gravel	Data not supplied	Gravel
Crops	Magnolias, Camellias, Lavatera, Spireas, Phygelius	Dahlia, Acer, Hydrangea, Fatsia Japonica	Data not supplied
Data collected	1 April – 25 Oct	9 April – 30 Sept	1 April – 13 Nov
Irrigation period	5 May – 14 Oct	17 Apr – 30 Sept	12 Apr – 11 Oct

Water use summary

Irrigation measurements were made at each nursery by installing a mechanical water meter in the supply pipe immediately before the bed being monitored. The meter reading was recorded manually by nursery staff each day, together with the duration of the watering event. The data supplied has been used to estimate the monthly usage throughout the 2001 growing season. In each data set there were occasional missing or anomalous readings. In such cases, values have been interpolated from the patterns of surrounding information.

The volume of water recorded was converted into millimetres of water applied to each bed by calculating the effective irrigation, i.e. the total volume supplied less the water sprayed outside the bed, divided by the total bed area. For the outdoor beds and the covered bed in nursery 2, the proportion of water lost outside the bed was determined geometrically from the number, arrangement and distribution radius of the spray nozzles as compared with the bed. The distribution of water from each nozzle was assumed to be linear across the radius. For the covered beds in nurseries 3 and 4, losses are constrained by the walls of the tunnel. It is assumed therefore that all water applied falls onto the bed. In nursery 2, the covered bed is within a much larger glasshouse and so the geometric approach was used.

The monthly average amount of water put onto the outdoor bed by irrigation each watering event was calculated by dividing the total millimetres of water applied by irrigation each month by the number of watering events. These are shown in
Table 8.1.

Table 8.1 Monthly average irrigation per watering event

	Nursery 2		Nursery 3			Nursery 4	
	Covered	Outdoor bed	Covered	Outdoor A	Outdoor B	Covered	Outdoor bed
Month	Irrigation (mm)	Irrigation (mm)	Irrigation (mm)	Irrigation (mm)	Irrigation (mm)	Irrigation (mm)	Irrigation (mm)
April	3.6		2.1			4.4	0.0
May	2.7	2.7	2.7	5.2	3.3	20.3[1]	7.8
June	5.0	2.7	4.2	5.5	4.9	7.5	6.0
July	3.6	3.1	5.8	7.6	4.6	9.1	8.5
Aug.	4.5	2.7	4.7	6.7	4.9	6.3	7.2
Sept.	5.0	2.4	3.7	7.0	5.0	4.7	6.0
Oct.	4.5					6.0	

1. The figures for May include one event significantly higher than all others for which no explanation is given.

The daily averages are calculated as the total millimetres of water applied each month, divided by the number of days. For the outdoor beds, rainfall is included. These are shown in Tables 8.2-8.4.

Table 8.2 Daily averages for nursery 2

	Covered bed	Outdoor bed		
Month	Irrigation (mm)	Irrigation (mm)	Rainfall (mm)	Total (mm)
April	0.9			
May	1.8	2.2	1.1	3.3
June	2.5	2.7	0.9	3.6
July	1.8	2.4	3.0	5.4
August	1.9	2.2	3.2	5.4
September	1.5	0.9	3.6	4.5
October	0.9			

Table 8.3 Daily averages for nursery 3

	Covered bed	Outdoor bed A			Outdoor bed B		
Month	Irrigation (mm)	Irrigation (mm)	Rainfall (mm)	Total (mm)	Irrigation (mm)	Rainfall (mm)	Total (mm)
April	0.7						
May	2.6	4.4	0.6	5.0	2.8	0.6	3.4
June	4.0	4.4	1.5	5.8	4.2	1.5	5.6
July	5.4	7.3	1.3	8.6	4.4	1.3	5.7
August	4.3	5.4	2.0	7.4	3.9	2.0	6.0
Sept.	3.1	5.8	0.5	6.3	4.3	0.5	4.7

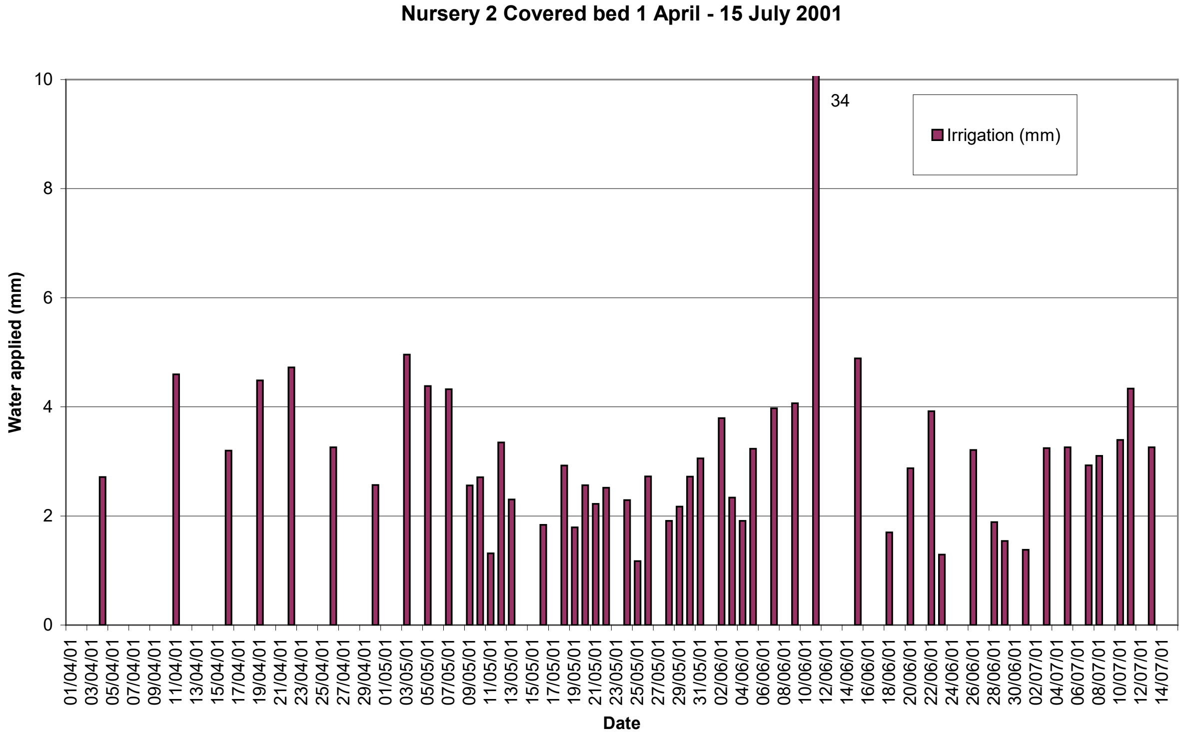
Table 8.4 Daily averages for nursery 4

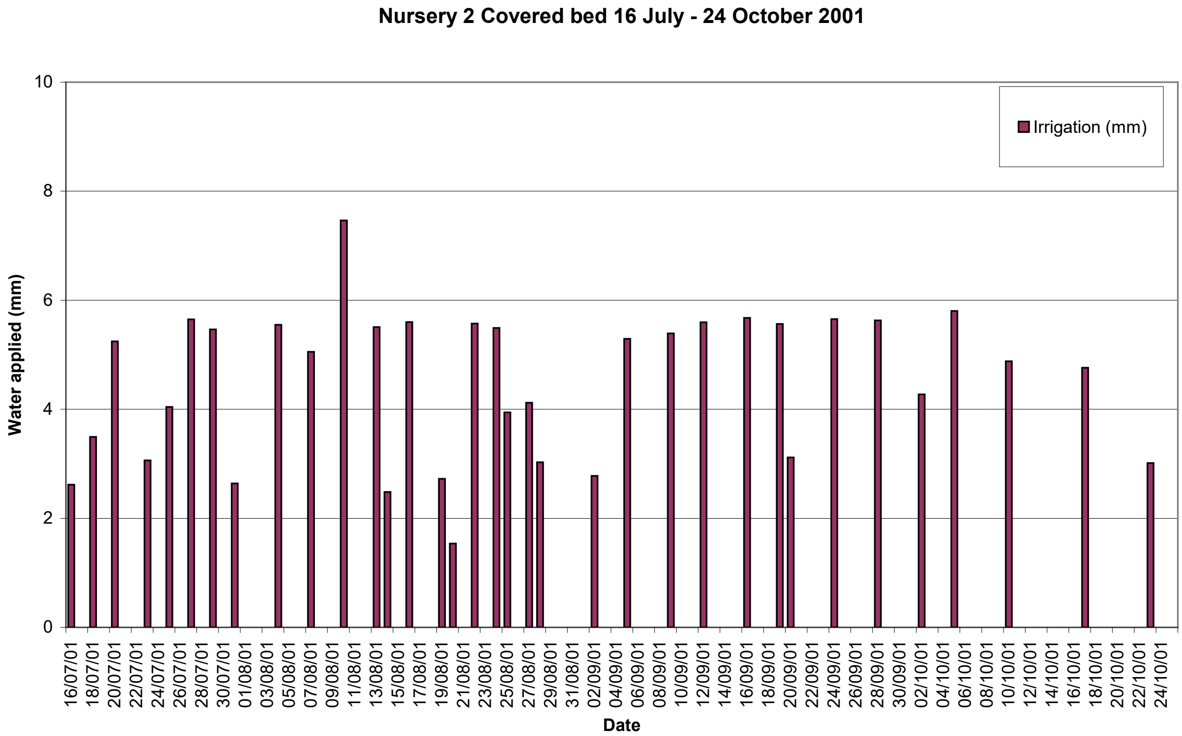
	Covered bed	Outdoor bed		
Month	Irrigation (mm)	Irrigation (mm)	Rainfall (mm)	Total (mm)
April	0.3		2.9	2.9
May	3.9[1]	2.5	0.8	3.3
June	2.3	4.4	1.6	6.0
July	3.5	7.4	0.7	8.1
August	2.8	4.2	4.2	8.4
September	1.4	2.0	2.7	4.7
October	0.6			

1. The figures for May include one event significantly higher than all others for which no explanation is given.

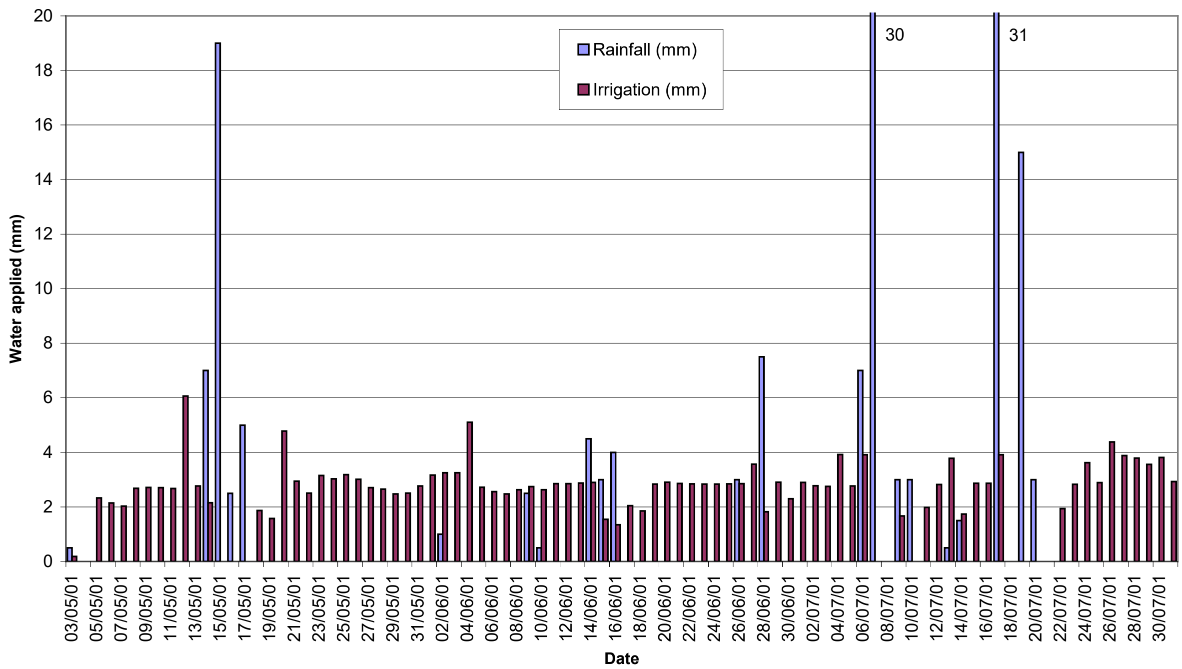
Histograms for the daily figures are presented in Appendix A. Also included are plots of the irrigation for the outdoor beds and mean daily temperature. As with the previous year, few conclusions can be drawn from this except the broad and obvious comment that in periods of high temperatures irrigation is increased either in intensity or frequency. The frequency or intensity reduces in cooler weather.

APPENDIX A DETAILED WATER USE DATA

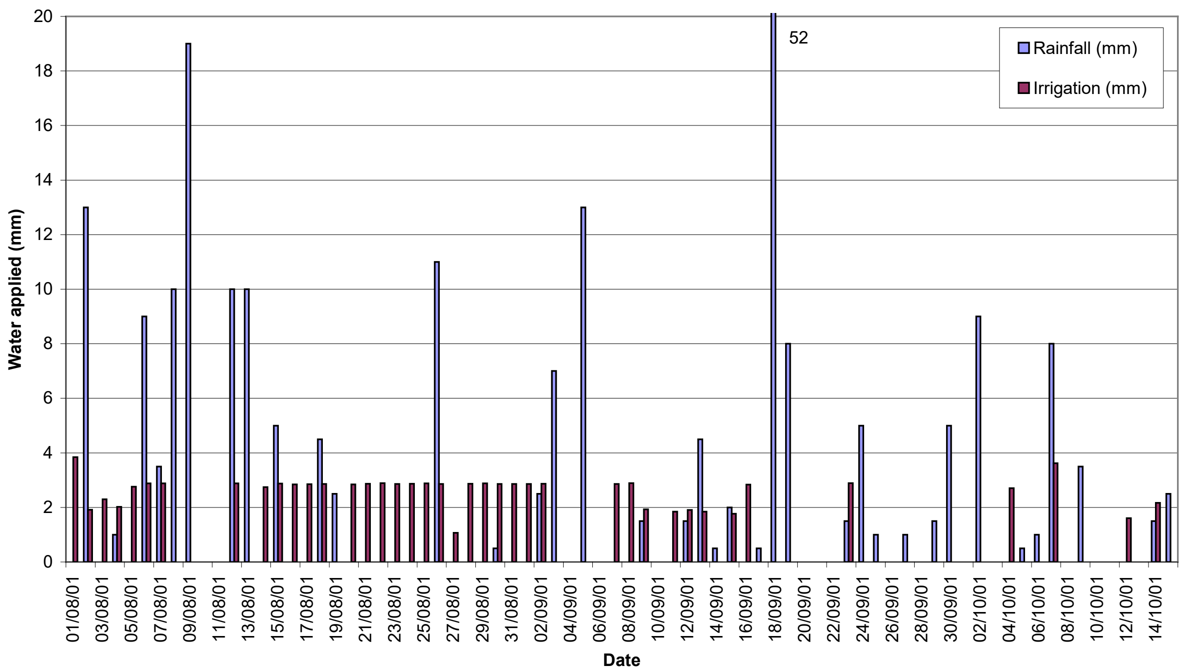




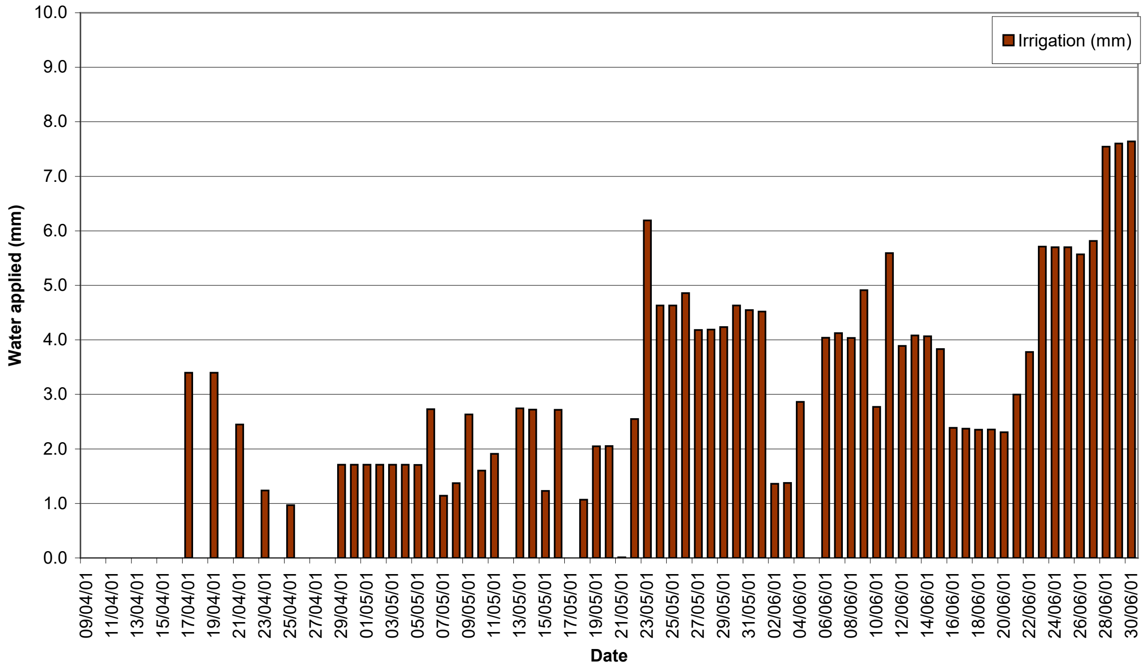
Nursery 2 Outdoor bed 1 May - 30 July 2001



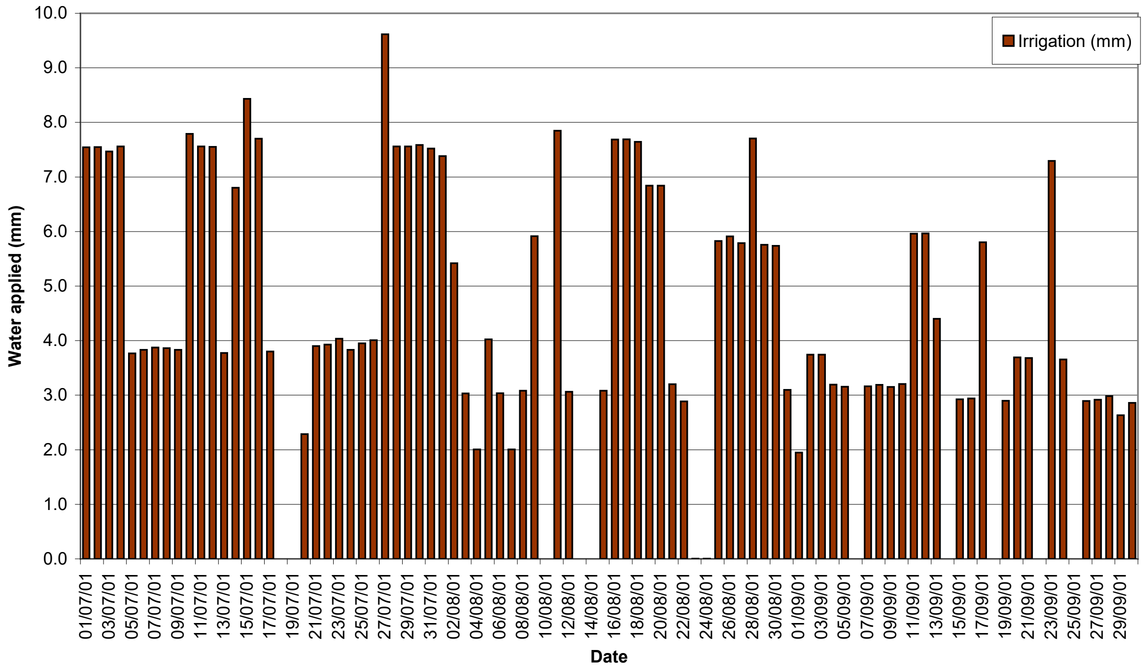
Nursery 2 Outside bed 1 August - 14 October 2001



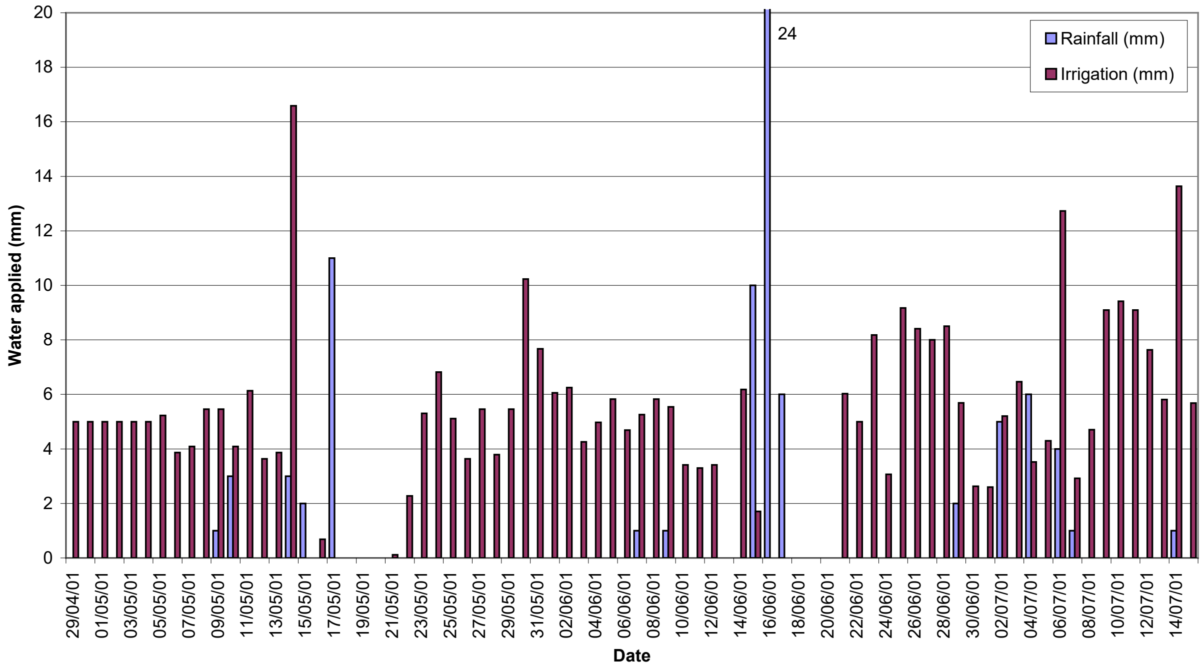
Nursery 3 Covered bed 9 April to 30 June 2001



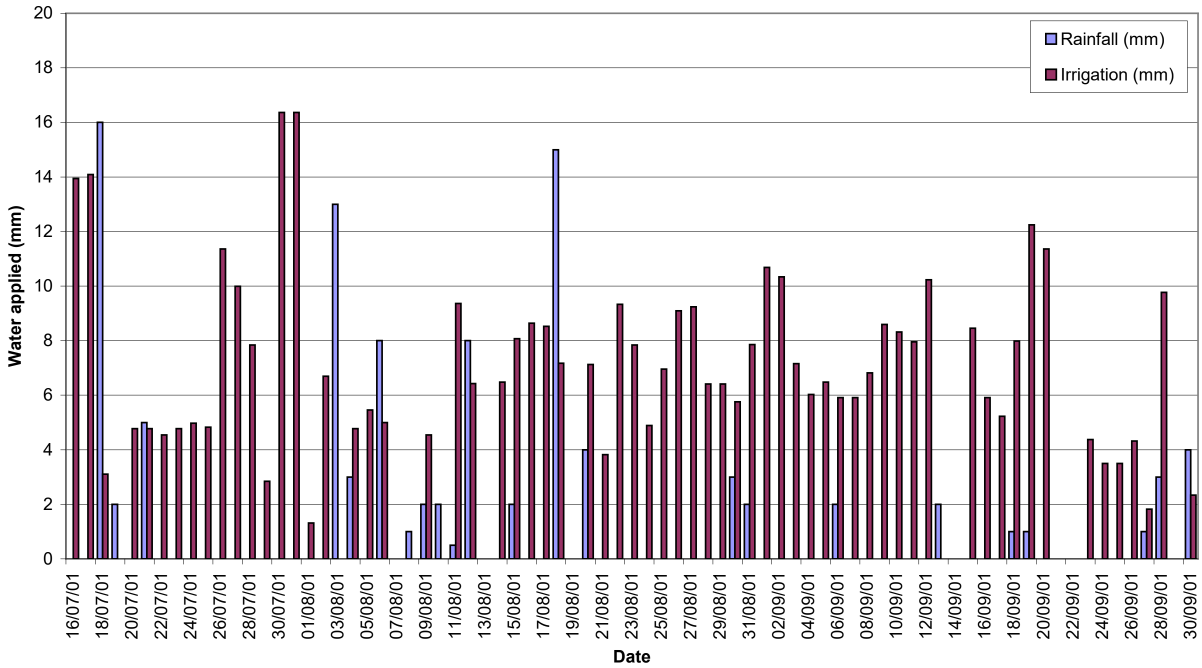
Nursery 3 Covered bed 1 July to 30 September 2001

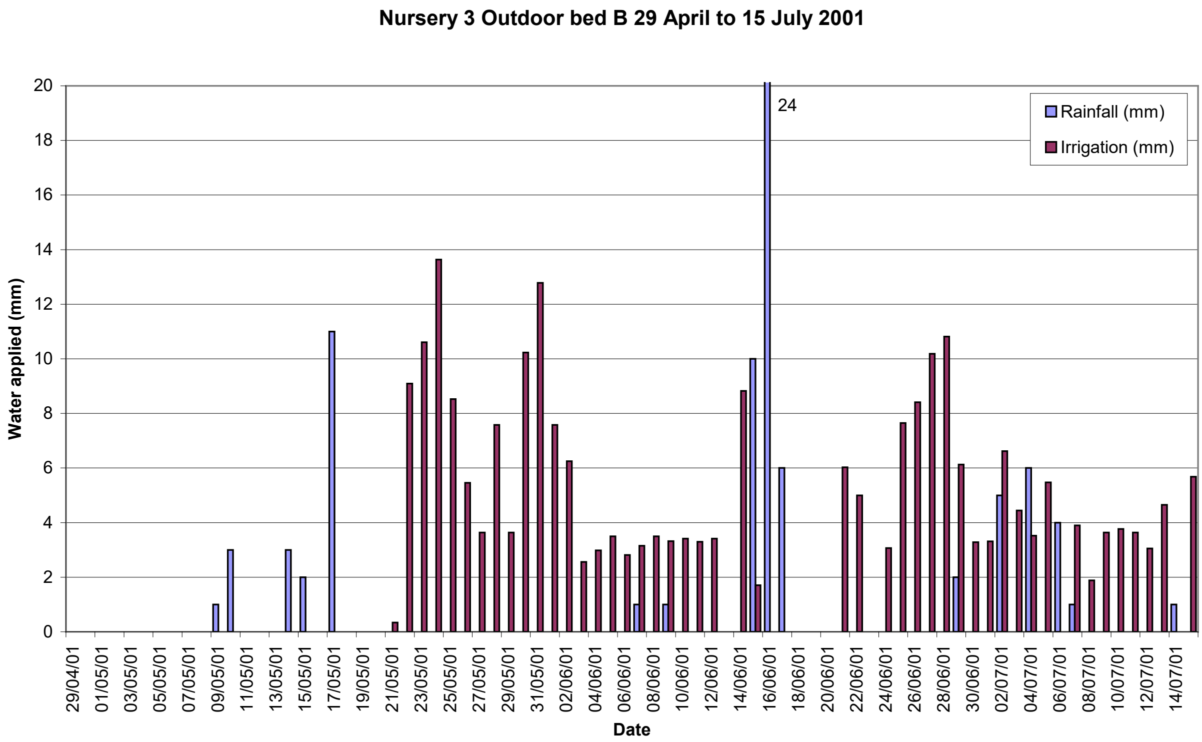


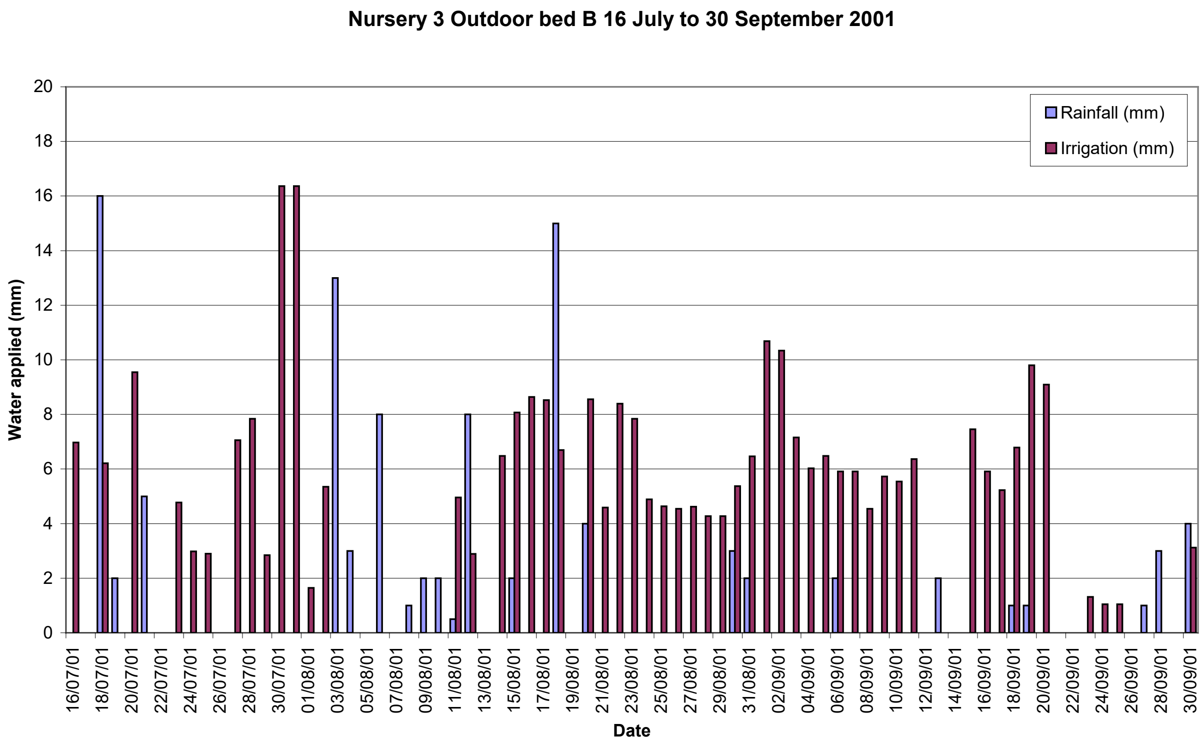
Nursery 3 Outdoor bed A 29 April to 15 July 2001



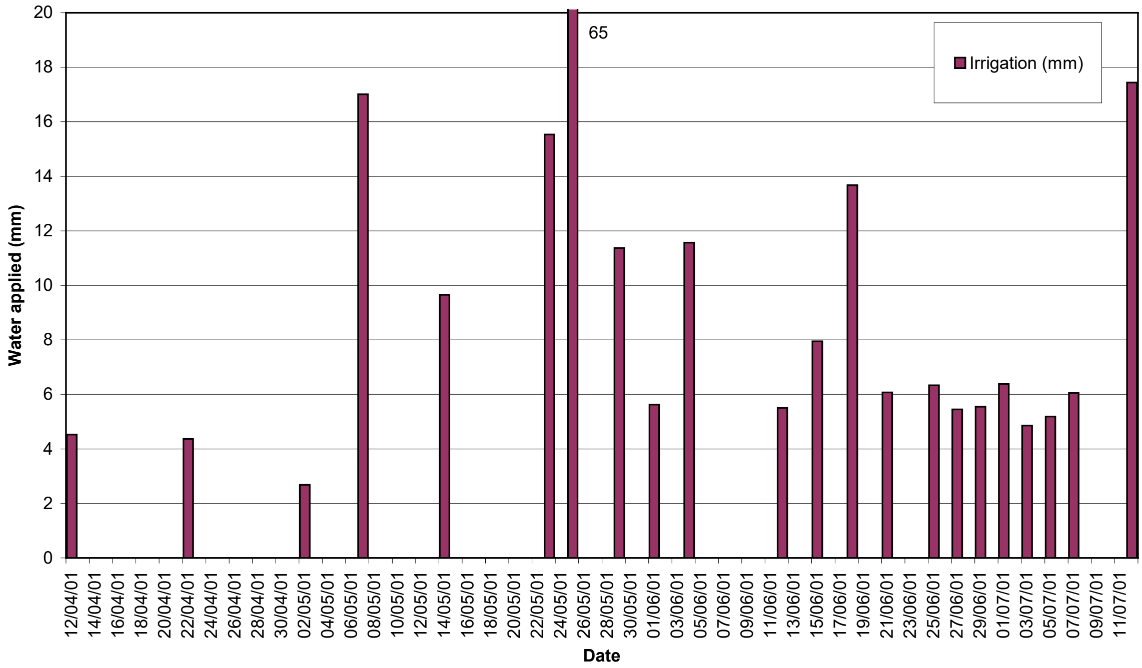
Nursery 3 Outdoor bed A 16 July to 30 September 2001



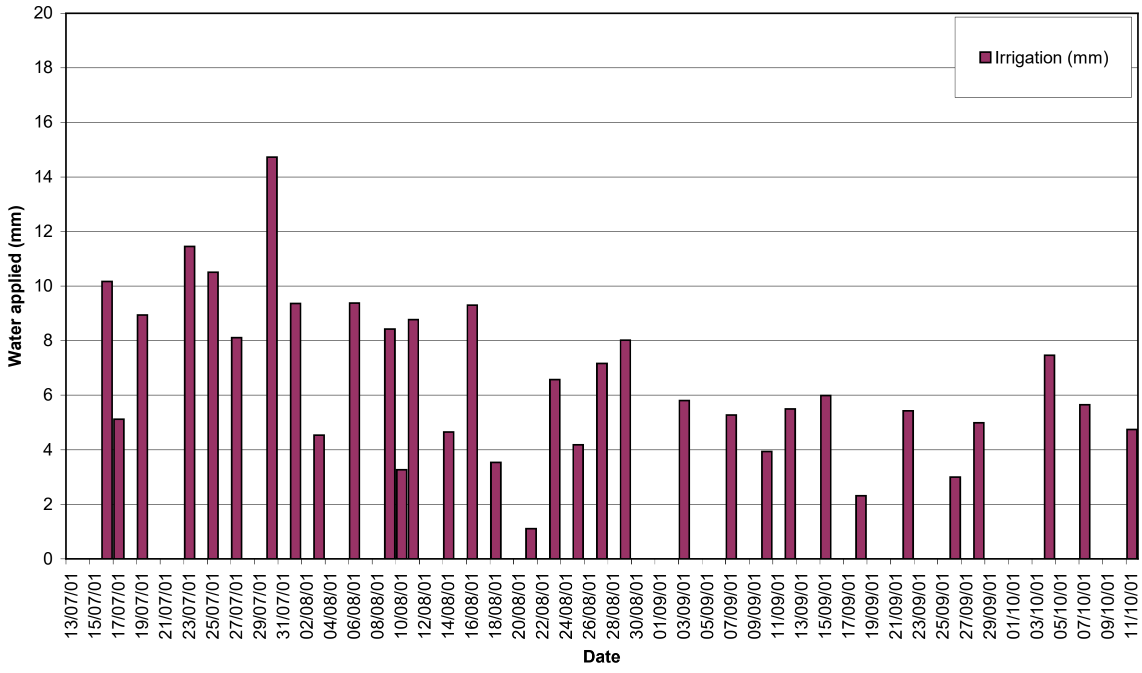

Nursery 3 Outdoor bed B 29 April to 15 July 2001
Water applied (mm)
Date
24
Rainfall (mm)
Irrigation (mm)


Nursery 3 Outdoor bed B 16 July to 30 September 2001
Water applied (mm)
Date
Rainfall (mm)
Irrigation (mm)

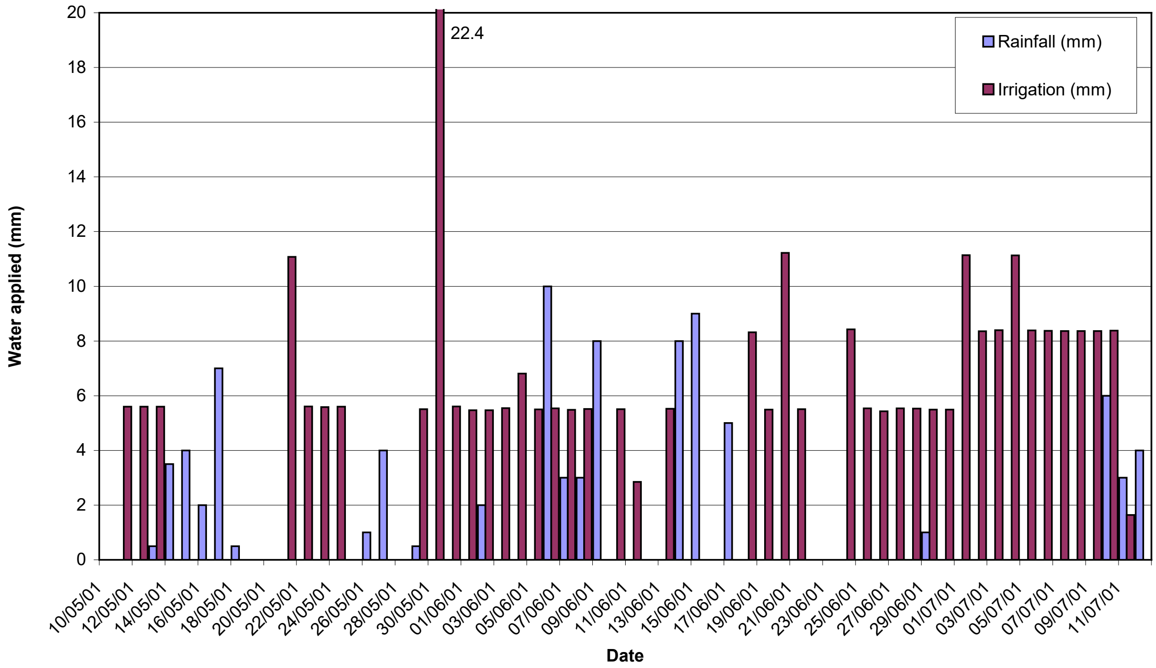
Nursery 4 Covered bed 12 April - 12 July 2001



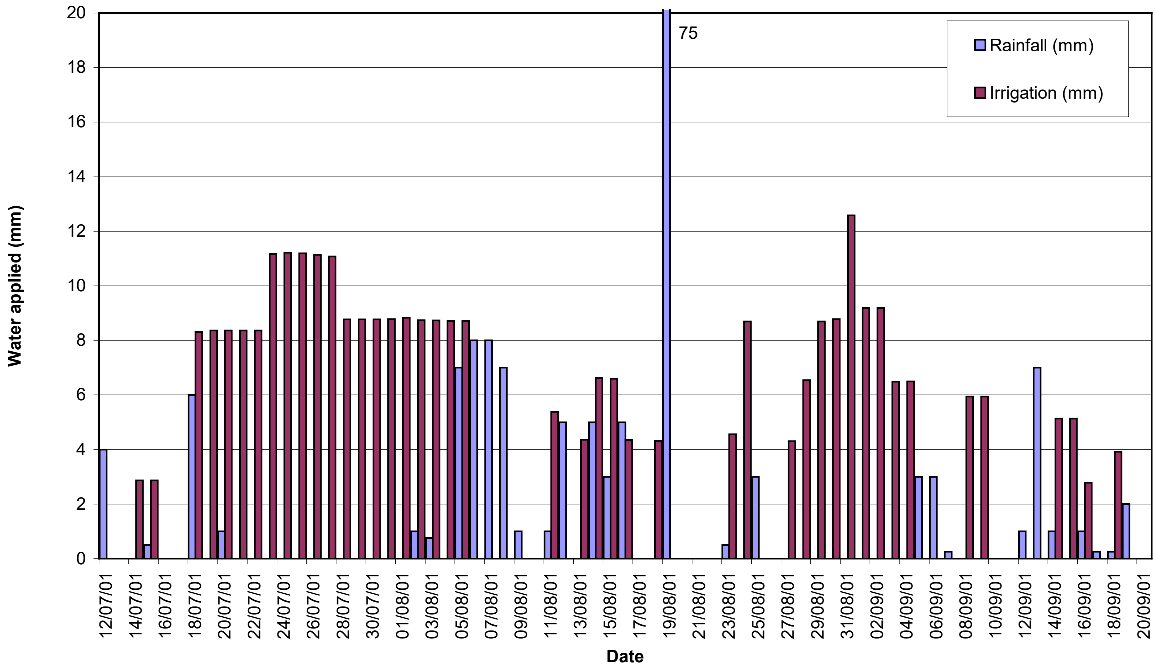
Nursery 4 Covered bed 13 July - 11 October 2001

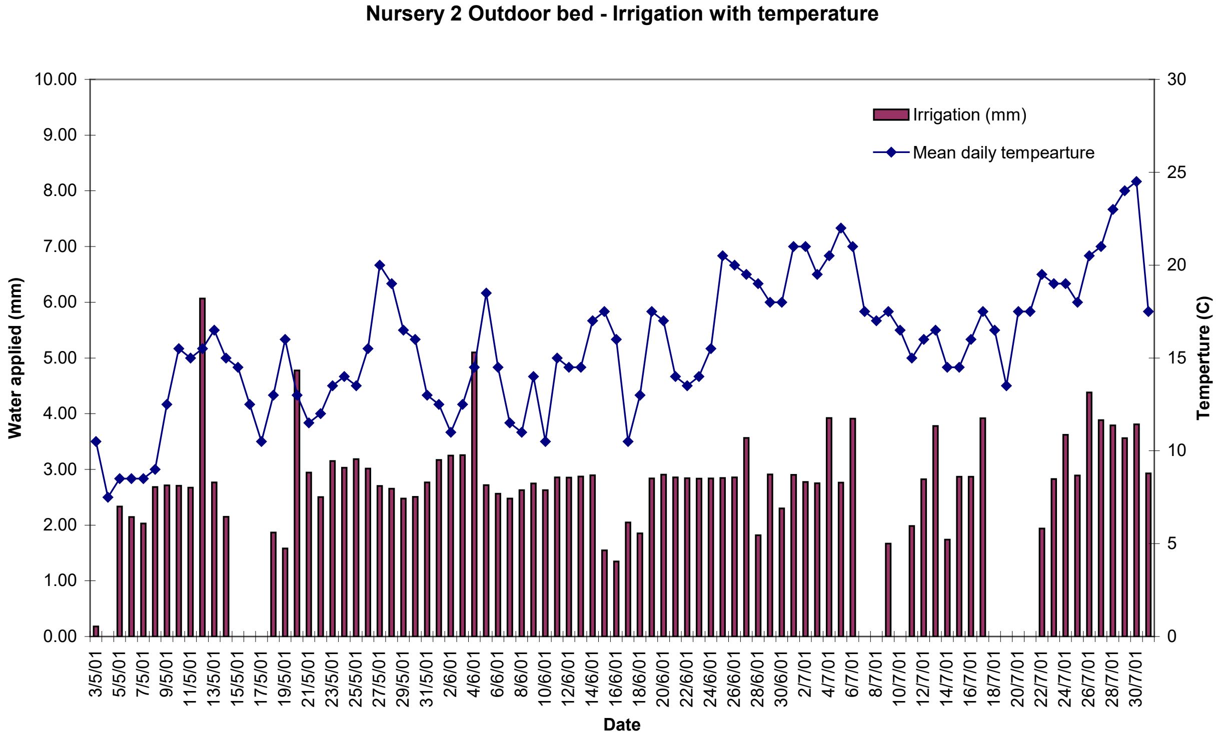


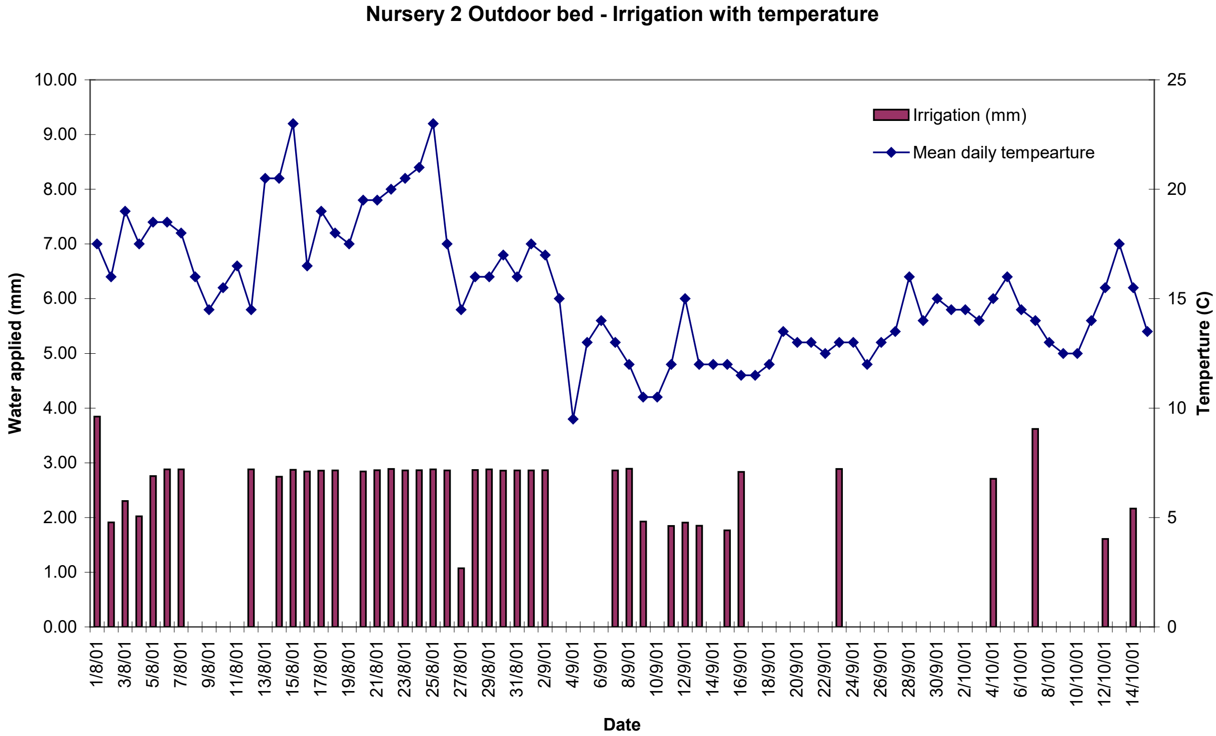
Nursery 4 Outdoor bed 10 May - 11 July 2001



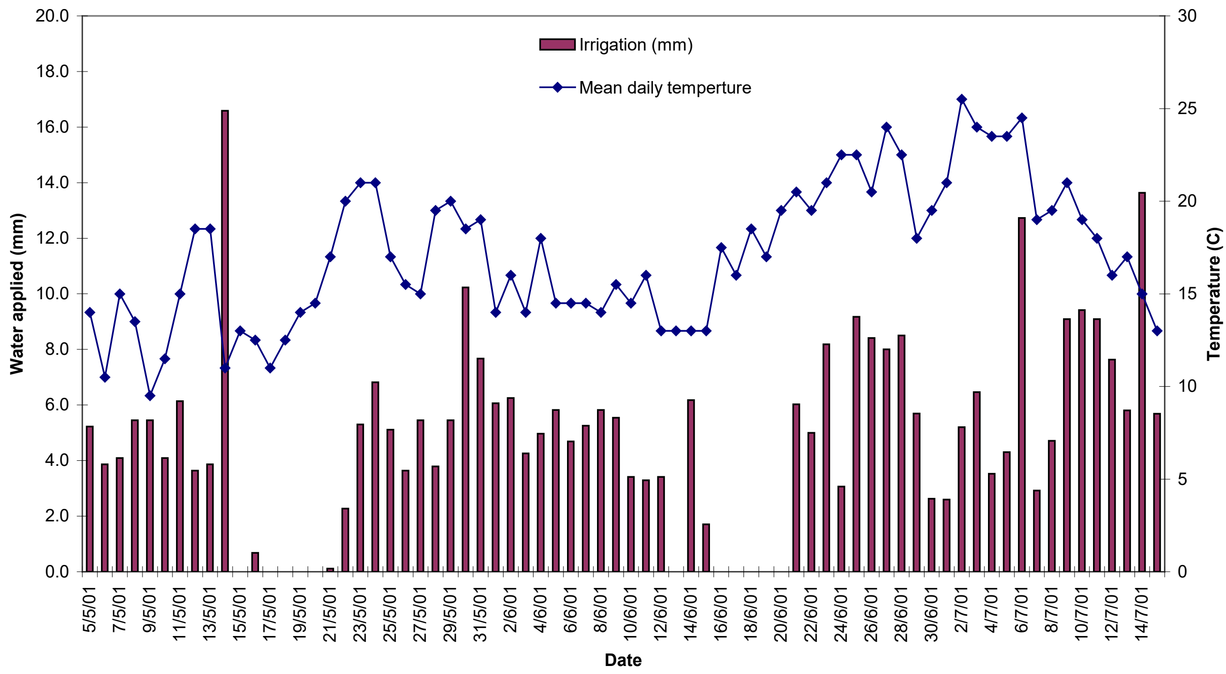
Nursery 4 Outdoor bed 12 July - 20 September 2001



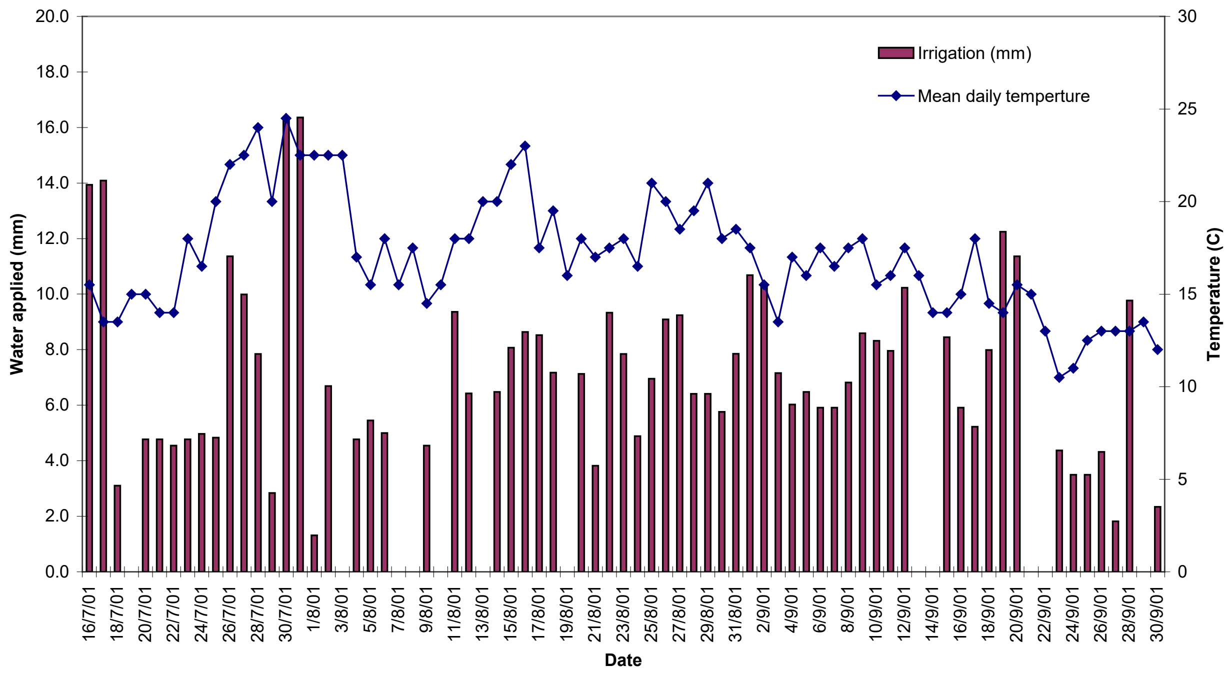

Nursery 2 Outdoor bed - Irrigation with temperature
Irrigation (mm)
Mean daily tempearture
Water applied (mm)
Temperture (C)
Date


Nursery 2 Outdoor bed - Irrigation with temperature
Irrigation (mm)
Mean daily tempearture
Water applied (mm)
Temperture (C)
Date

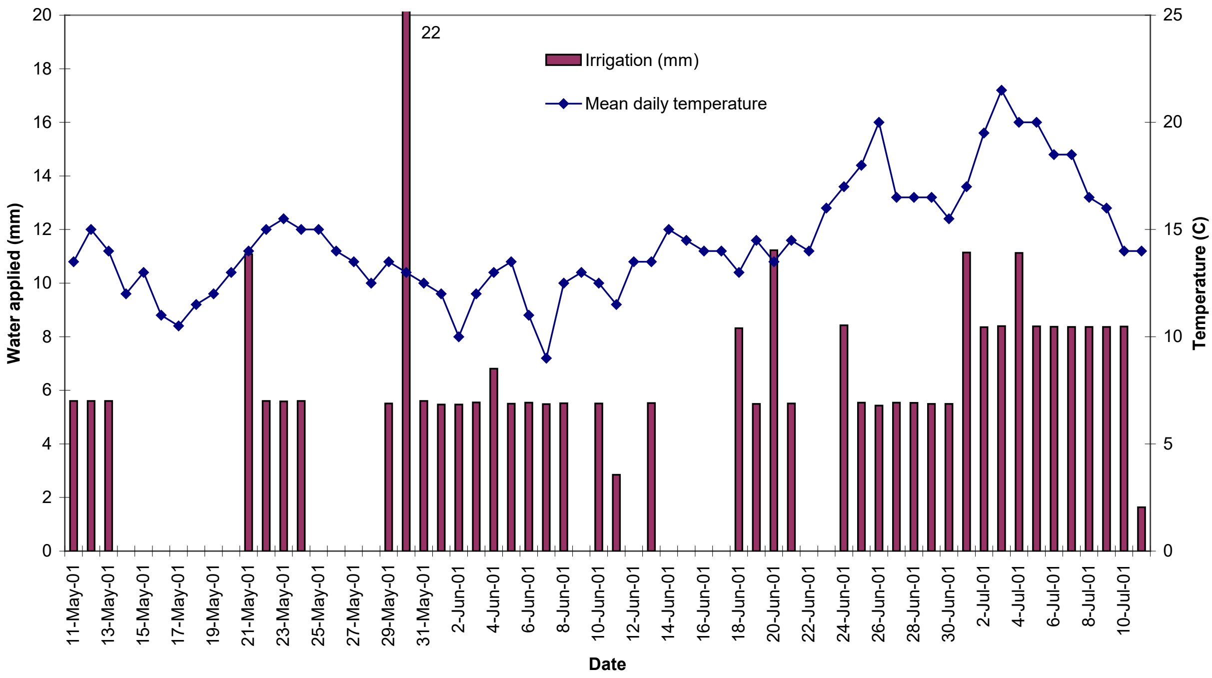
Nursery 3 Outdoor bed A - Irrigation and temperature



Nursery 3 Outdoor bed A - Irrigation and temperature



Nursery 4 Outdoor bed - Irrigation and temperature



Nursery 4 Outdoor bed - Irrigation and temperature