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Project leader:	**Dr R.S. Harrison-Murray**
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IMPROVING IRRIGATION EFFICIENCY FOR NURSERY STOCK IN CONTAINERS

R.S. HARRISON-MURRAY
HRI - EAST MALLING

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RELEVANCE TO NURSERYMEN AND PRACTICAL APPLICATION

Application

The objective of this project was to test the feasibility of developing a simple but objective means for growers to decide, on a day to day basis, the amount of irrigation required by container plants. A number of possible methods were identified ranging from a very simple "bucket evaporimeter", to an electrical sensor of evaporative demand known as the "evapo-sensor".

At present growers should regard these methods as an aid to their current irrigation management practice, but with further development and testing, automatic systems are envisaged.

Summary

Water costs are rising and there is pressure to control the pollution caused by leaching. Low capital cost makes overhead sprinkler irrigation popular, despite its wastefulness, and a tendency for growers to err on the side of overwatering exacerbates this waste. This report examines the feasibility of improving the efficiency of overhead irrigation by using estimates of how much water plants are using to regulate the amount applied.

Thirteen subjects provided a range of different types and sizes of plants. Water used by each plant was measured by weighing daily, afterwards adding water to restore the original weight and bring the medium back to container capacity.

Variability of plant water use from day to day

For the many growers who irrigate daily, the aim must be to apply just the amount of water that plants have used in one day. Figure 1 shows how variable this can be.

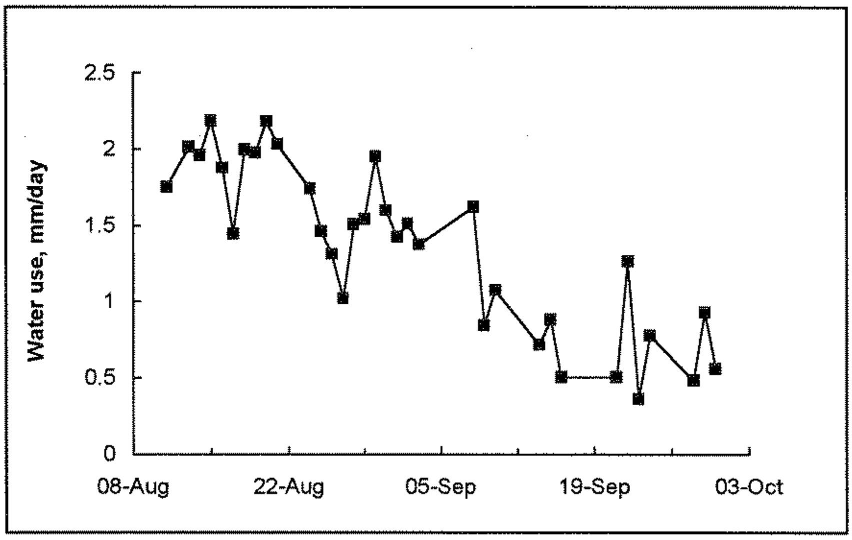

Figure 1. Variation in daily water use in 1993 (average of 10 subjects)

Water use varied between different days by up to 6 times. Some of this was associated with a gradual seasonal decrease but, even between consecutive days, water use varied by up to 3.5 times. This implies that if irrigation timers were set to deal with the most drying days, then up to 250% more water than required would be applied on other days. These results highlight the waste that probably results from the widespread use of regular timed irrigation.

Estimates of evapotranspiration

A number of simple physical methods of **estimating** plant water use were compared with the measured values. The methods included meteorological measurements (e.g. solar radiation) and values derived from them (Penman estimate), evaporation from a free water surface (the various evaporimeters), and an electrical evaporation sensor (the evapo-sensor). The last of these is an East Malling invention for the control and monitoring of propagation environments, developed with the help of HDC funding, .

Overall, the evapo-sensor was the most consistent, always accounting for more than 86% of the variation in measured plant water use (Table 1, Fig. 2). Being electrical, it also presents opportunities for the development of automatic control systems.

The simplest method was the 'bucket evaporimeter', consisting of a black plastic bucket, part-filled with water, from which evaporation was measured by weighing. This method accounted for 90% of the variation on rain-free days, but became very erratic when it rained. This problem could probably be avoided by a simple change in design.

Table 1. Correlation of plant water use with the different evapotranspiration estimates.

Method	Variation accounted for
Evapo-sensor	86%
Pan evaporimeter	85%
Solar radiation	77%
Leaf-model evaporimeter	76%
Penman estimate	72%
"Bucket" evaporimeter	67%
Mean air temperature	38%
Mean wind speed	8%

Using evapotranspiration estimates to regulate irrigation

These methods indicate how the irrigation requirement varies from day to day, rather than the actual amount, which also depended on the size and spacing of plants (Fig. 3).

However, considering the wide range of subjects involved, differences were surprisingly small. Furthermore, as an **aid to existing methods** of deciding how much water to apply, it is not essential to know how the water use estimate relates to the actual water use of particular species. Also, all plants responded similarly to the day to day changes in weather (e.g. Fig. 4).

With sprinkler irrigation over gravel or Mypex, the quantity to be applied is also directly affected by **pot spacing** because water falling between pots is wasted. For instance, with large plants spaced at 35 x 35cm in 2 litre pots, more than 80% would be wasted. Before irrigation can be controlled entirely on the basis of evapotranspiration estimates it will therefore be necessary both to calibrate the chosen method for the plants being grown, and also to allow for the wastage caused by water failing to reach the containers.

Wide-spaced plants used much less water per unit area than those standing pot-thick, despite using substantially more per plant. However, plant water use was only slightly increased at the edge of a block, and by standing on dry Mypex rather than moist sand.

Summary of practical conclusions

1. Variations in water use from day to day are too large to ignore: a fixed irrigation period every day is likely to be very wasteful.

2. There are a number of ways that water use can be estimated accurately enough to be useful. Of these the evapo-sensor looks most promising but is still in the process of being commercially developed. The simplest is the "bucket evaporimeter" which some growers may wish to test immediately.

3. Variation in water use between plants of different size and species is also too large to ignore. The range of plants within each irrigation area should therefore be minimised.

4. Overhead irrigation is particularly inefficient when containers are spaced out. Therefore, drip irrigation should be considered for larger plants.

Future work

Now that the feasibility of this approach has been proved, it needs to be tested under nursery conditions, initially as an aid to manual management of irrigation, eventually in an automated system.

Preliminary results suggest that, by supplying somewhat less than the plants are capable of using, water use can be reduced without loss of quality. This needs thorough investigation for a range of important crops.

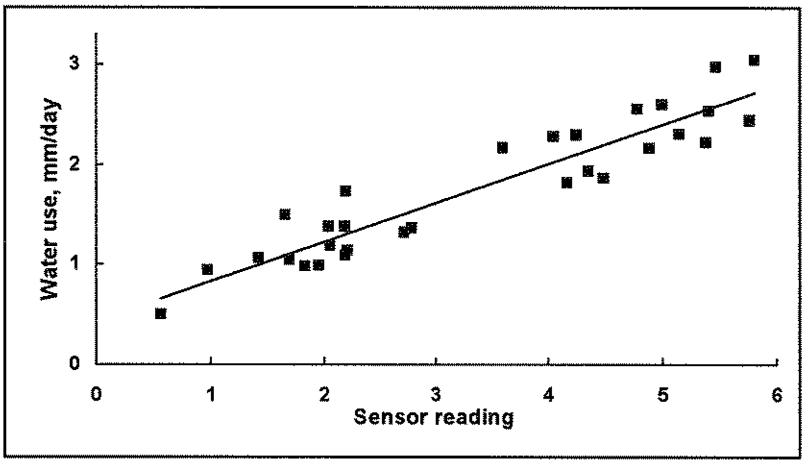

Figure 2. Relation between water use by the plants and evapo-sensor reading.

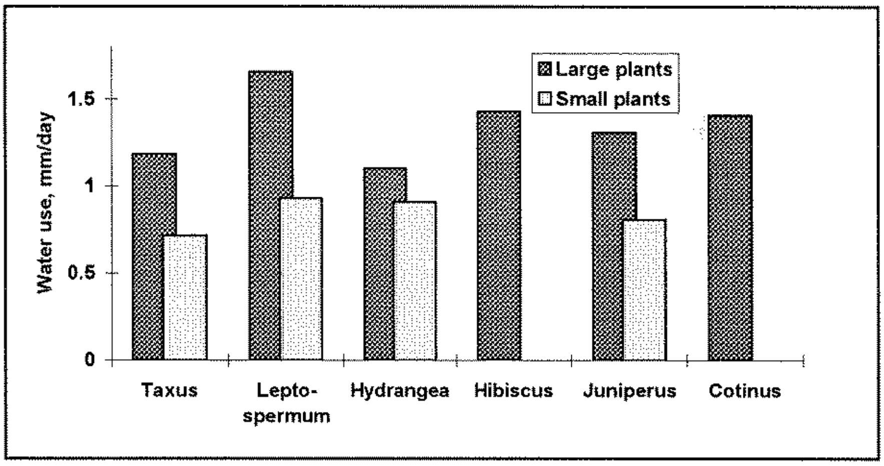

Figure 3. Variation in water use between subjects.

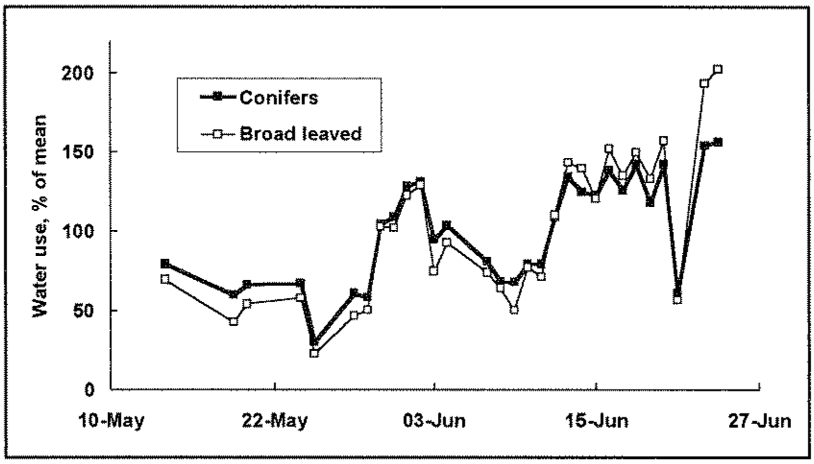

Figure 4. Close parallel of variation in water use in different types of plants. Data are expressed as percentage of the mean for each type.

EXPERIMENTAL SECTION

Introduction

This project examined the feasibility and potential benefits of estimating irrigation requirements of containers from physical measurements of evaporative demand on a day to day basis.

A series of dry summers has helped focus the attention of growers on the need to improve the efficiency of water use. Water costs are rising and it is in short supply in some areas, yet overhead sprinkler irrigation is the standard method of applying water in the industry, despite it being inherently wasteful, especially for plants in containers. Water that falls between the containers generally runs to waste, and much water falls on bare areas and roadways.

The situation is exacerbated by the problem of deciding how much water is needed. Evidence suggests that the current, largely intuitive, methods of regulating the amount of water applied generally result in excessive irrigation, largely because the effects of under-watering are so much more visible than those of over-watering. The quality of some subjects almost certainly suffers as a result.

Capillary sand beds are less wasteful but the cost of such beds is high, making rapid conversion of the industry to their use unrealistic. Less costly capillary systems were the subject of complementary work at Efford (HNS38). The work described in this report is aimed primarily at the industry's current facilities and the need to reduce waste where containers on gravel or Mypex are irrigated by overhead sprinkler.

This research tested the feasibility of providing growers with a simple and objective means of estimating water use by container plants as a basis for regulating irrigation. This approach is well established for field crops where it has been found that water loss from a uniform crop canopy is remarkably close to that from a free water surface. At the outset, two factors raised doubts whether the same approach would work for container plants. First, the restricted root zone volume of the container necessitates that water use be estimated accurately over a much shorter period than applies in the field. Second, variation in both the size of the plants, and the gaps between them, means that container beds do not present an extensive and uniform canopy.

Materials and methods

(i) Plant material and growing conditions

The material was selected with the help of the industry coordinator, to represent a wide range of sensitivity both to drought and to overwatering, as well as a range of size, form and growth habit. In many species, two sizes of plants were included, some in their final season and approaching saleable size (referred to as 'large'), others one year younger ('small'). The subjects are listed below:

Species	Sizes
Juniperus x *media* 'Pfitzeriana Aurea'	2 sizes (1&3 litre)
Taxus baccata	2 sizes (both 4 litre)
Leptospermum scoparium 'Snow Flurry'	2 sizes (both 2 litre)
Hibiscus syriacus 'Woodbridge'	1 size (3 litre)
Hydrangea macrophylla 'Madame Emile Mouillère	2 sizes (1&3 litre)
Cotinus coggygria 'Royal Purple'	1 size (2 litre)
Forsythia x *intermedia* 'Lynwood' LA 79	1 size (2 litre)
Berberis x *stenophylla*	1 size (2 litre)
Ceonothus arboreus 'Autumnal Blue'	1 size (2 litre)

All were in peat-based growing media with CRF. Supplementary liquid feeding was applied as necessary. Except where stated otherwise, plants were grown at a spacing appropriate to their size, on Efford-specification subirrigated capillary sand beds.

(ii) Measurement of plant water use (evapo-transpiration)

Before starting measurements, and after any break in recordings, the growing medium was brought to container capacity by generous hand watering followed by overnight drainage on the sand bed. The pots were then stood in pot-saucers to separate them from the sand so that the loss of weight of the pot + plant would be an accurate measure of evapotranspiration.

Weights were measured at approximately 24 hour intervals, temporarily transferring the plants to the shelter of a glasshouse to achieve a precision of $\pm$ 1g. Afterwards, water was added to restore the original weight and thus bring the medium back to container capacity. By maintaining container capacity in this way, water use would not have been limited by water supply so that the measurements can be taken to indicate **potential evapotranspiration** of the plants concerned.

In processing the data, adjustment was made for any rainfall recorded. To minimise errors caused by wind-driven rain hitting and running down the sides of the pot, a polythene "skirt" was fitted to prevent it reaching the saucer. Any drainage water which collected in the saucer was removed before recording the starting weight for the next 24 hour period. To avoid potentially large errors, no water use figure was calculated if drainage water nearly filled the saucer.

Rates of water use are expressed per 24 hour day and, by taking into account the spacing of the individual subjects, per unit area of ground covered. They are expressed in mm, to facilitate comparison with rainfall or irrigation figures. Taking the volume of 1g of water as 1cm^3,

1 kg per sq. m	= 1mm
	= 10 cu. m per ha
	= 10000 l per ha
	= 14.3 cu.ft. per acre
	= 891 gal. per acre

(iii) Potential evapotranspiration estimates

The following methods of estimating potential evapotranspiration (i.e. water use by plants with non-limiting water supply, abbreviated to ET_p) were tested:

(a) Pan evaporimeters: A large circular stainless steel water tank located on an area of grass at the East Malling Meteorological Station about 1 mile from the container bed. Change in height of the water level was measured daily with a hook gauge readable, with care, to $\pm$ 1mm. Another pan evaporimeter was located as close as possible to the container bed, on an area of rough grass next to a polythene tunnel.

(b) Bucket evaporimeter: A black plastic bucket, height 25cm, diameter tapering from 30 to 24cm, filled to a depth of 11.5cm with water, and covered with chicken wire to exclude animals. Evaporation was measured by daily weighing, water being added afterwards to restore the original weight. Weighing to $\pm$ 1g was equivalent to a precision of $\pm$ 0.02 mm.

(c) Leaf model evaporimeter: A physical model of a leaf, evaporation being registered as a change in the volume of water held in a calibrated reservoir. Originally devised for monitoring propagation environments, it has been described in detail elsewhere (R.S. Harrison-Murray, 1991). To adapt it for the much higher evaporation rates outdoors, the evaporating area was reduced greatly. It is visible in the foreground of Figure 5.

(d) Evapo-sensor: An electrical sensor of potential evapotranspiration, invented at East Malling and developed for the control of fog and mist propagation systems with the help of previous HDC funding (Harrison-Murray *et. al.* 1993). Unlike any other electrical sensor it is sensitive to all the factors that influence transpiration i.e. humidity, radiation, wind, temperature, and leaf wetting. It is also visible in Figure 5. An automatic data logger (Delta-T Devices) monitored the output of the sensor, storing the average at 30 min. intervals. Small negative values often recorded at night were converted to zeroes when calculating daily averages from the logged data.

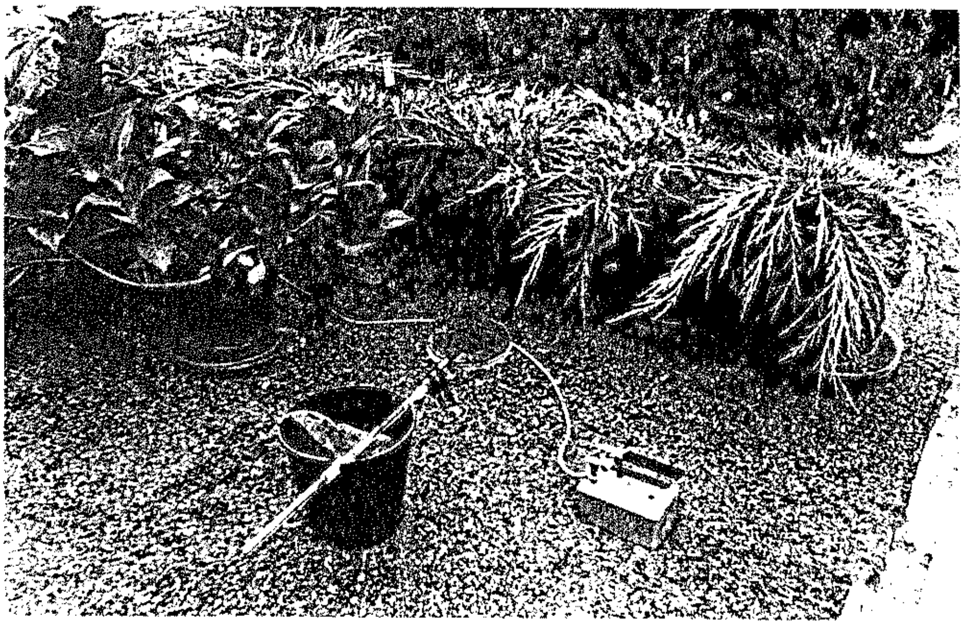

Figure 5. The evapo-sensor (right) and leaf-model evaporimeter (left), in front of some of the experimental plants.

(e) Automatic weather station data: The meterological station attached to our glasshouse computer provided daily values of air temperature, wind speed, and solar radiation.

(f) Penman estimate: This is a well established method of estimating potential evapotranspiration mathematically from weather data. Daily values were provided by the East Malling meteorologist based on data collected about 1 mile from the container beds.

Definition of the 'measurement day': The 24 hour period over which these data were integrated was not consistent. For methods a(local), b, c, and d, it was the same as for the plant water measurements, generally from about 10:00 to the same time the following day. For the automatic weather station (method e) it was dawn to dawn. For the Penman estimate and the met. station pan evaporimeter, it was 9:00 to 9:00 GMT.

These differences reflect problems likely to be faced by growers wanting to use these methods. Where the method was such that the grower could collect his own data, it could be synchronised with the timing of his irrigation but this would not be the case for estimates provided as a service.

For experiment 3 only, additional radiation measurements were made, integrated over the same period as the plant measurements, using a data logger. This provided a comparison between radiation measurements and the evapo-sensor based on an identical 'measurement day'.

Adjustment for rainfall. Since pan and bucket evaporimeters were open to rainfall, readings were adjusted to compensate for this, based on a nearby rain gauge.

(iv) Outline of the main experiments

There were 3 main experiments, differing with respect to time of year and subjects included:

Experiment 1

Duration: 10 August - 5 November 1993

Subjects: Large and small plants of -
Taxus, Leptospermum, Hydrangea, Juniperus, Cotinus
Large plants only of -
Hibiscus

Replication: 2 plants of each subject, one at the edge of the bed, the other central

Experiment 2

Duration: 13 May - 24 June 1994

Subjects: Large and small plants of -
Taxus, Hydrangea, Juniperus, Cotinus
Large plants only of -
Hibiscus

Replication: 3 plants of each subject, one at the edge of the bed, two central

Experiment 3

Duration: 17 August - 18 September 1994

Subjects: Large *Juniperus* and small *Taxus, Hibiscus, Forsythia, Berberis*, and *Ceonothus*

Replication: One plant of each subject, located centrally

An additional radiation measurement (photosynthetic photon flux density), averaged over the same periods as used for the plant water use data, was included in this experiment.

(v) Outline of supplementary experiments

Additionally there were 3 supplementary experiments which looked in a preliminary way at other factors affecting rates of plant water use:

Experiment 4: on the effect of spacing

Duration: 20 - 27 July 1994

Subjects: Small *Forsythia*

Treatments: Spacing-
17.5 x 17.5 cm (pot thick)
35 x 35 cm

Replication: 12 plants at each spacing

Experiment 5: on the effect of standing surface

Duration: 1 - 9 August 1994
Subjects: Small *Forsythia*
Treatments: Standing surface-
sandbed
Mypex (over sandbed)
(both spaced at 35 x 35cm)
Replication: 12 plants on each surface

Experiment 6: on the effect of 'lean' watering

Duration: 15 Aug - 22 September 1994
Subjects Small *Forsythia*
Treatments: Restricted watering-
Full potential evapotranspiration
3/4 potential evapotranspiration
1/2 potential evapotranspiration
Replication: 2 plants per treatment

To avoid disturbance of the treatments by rain, plants were kept in a non-shaded polythene tunnel. The effect on plant growth was monitored by regular measurement of the length of leading shoots. At the end of the experiment the moisture status of the medium was measured with tensiometers and with the Rapitest moisture meter, while plant water status was assessed by measuring stomatal conductance with a porometer and leaf water potential with a pressure chamber.

Results

Fluctuation in the rate of water use

In experiment 1, water use declined about 4-fold over 3 months. In August, when measurements were started, water use of around 2 mm/day was recorded on many days, the average for the month being 1.75 mm/day. By September the average had halved to 0.93 mm/day and, towards the end of the month, most values were around 0.5 mm/day (Fig. 6). This progressive decline was clearly associated with the seasonal changes in weather conditions. Probably the most important was the reduction in solar radiation as both daylength and solar angle decreased. With this in mind, solar radiation is plotted alongside the water use data in Figure 6.

After a four week break in measurements, values recorded in late October / early November averaged 0.34 mm. By this time the deciduous species were losing their leaves, which would also have contributed to the further decline in water use. (This period was therefore excluded from Fig. 6.)

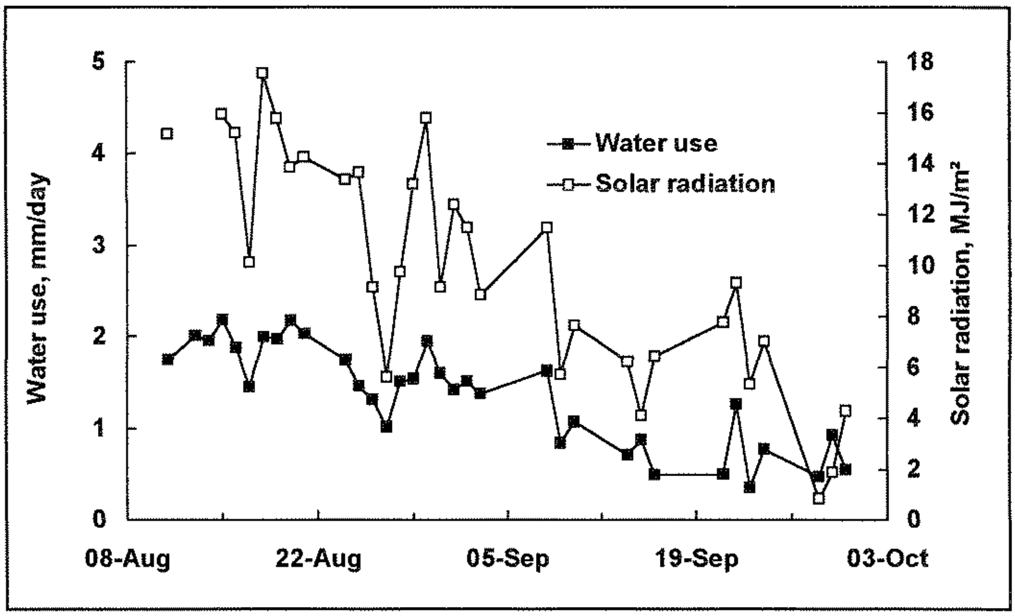

Figure 6. Variation in daily water use in 1993 (average of 10 subjects) plotted alongside solar radiation to show the broadly similarity.

Superimposed on the progressive seasonal change were very large day to day fluctuations. Considering only August and September, the maximum water use (2.19 mm/day on 15 August) was more than six times as much as the minimum (0.36 mm/day on 23 September). Even between succeeding days, there were many instances of a 2-fold difference and one example of a 3.5-fold difference.

The large seasonal variation associated with the first experiment was both an advantage and a weakness. It provided a very wide range of rates of water use against which to test the various ET_p estimates, but it risked identifying as suitable any method that was sensitive to daylength.

Experiment 2 was conducted to check whether the methods of estimating ET_p which appeared promising in the first experiment would perform equally well when daylength was more or less constant. Under these circumstances, factors other than solar radiation, particularly wind, would tend to be more important. From mid-May to late-June very large day to day variations in water use were observed (Fig. 7), the extremes again varying 6-fold.

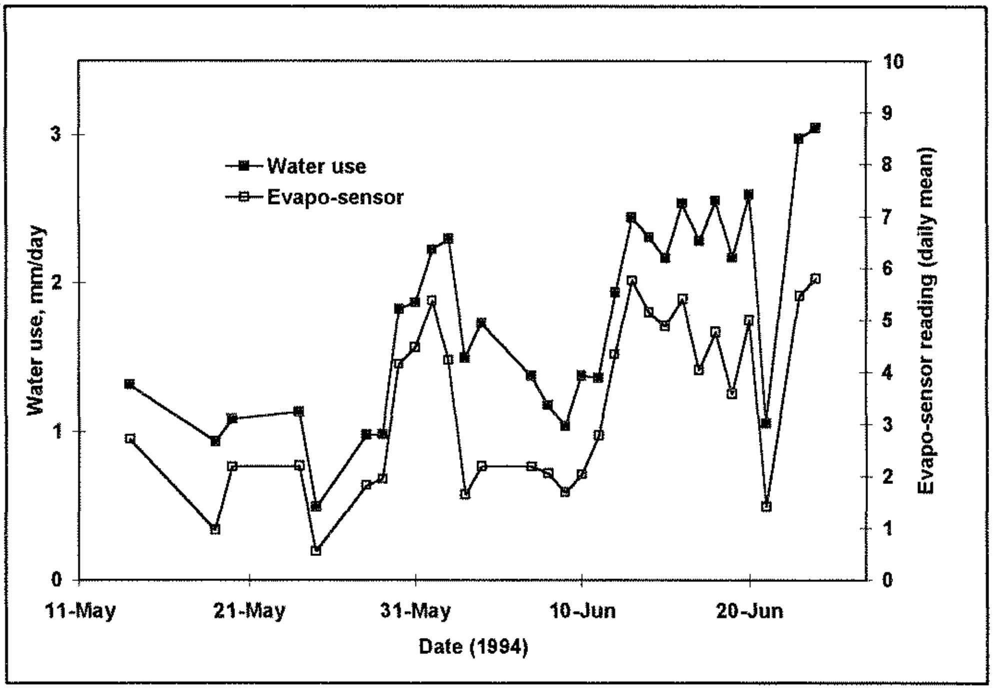

Figure 7. Variation in daily water use in 1994 (average of 9 subjects) plotted alongside evapo-sensor readings to show the close similarity.

Correlation between estimates and actual water use

The rough parallel between the lines in Figure 6 suggests that solar radiation measurements offer one way of estimating water use from container plants, while the rather closer parallel in Figure 7, suggests that evapo-sensor readings may be even better. Plotting the daily values of water use *against* evaposensor reading provides a clearer picture of how closely it relates to plant water use (Fig. 8). The statistically fitted line represent the best possible fit of a straight line to the data, while the scatter of the points around the line measures the size of errors we should expect when using it to estimate plant water use. By contrast, Figure 9 shows that wind speed would not be a good basis for estimating water use.

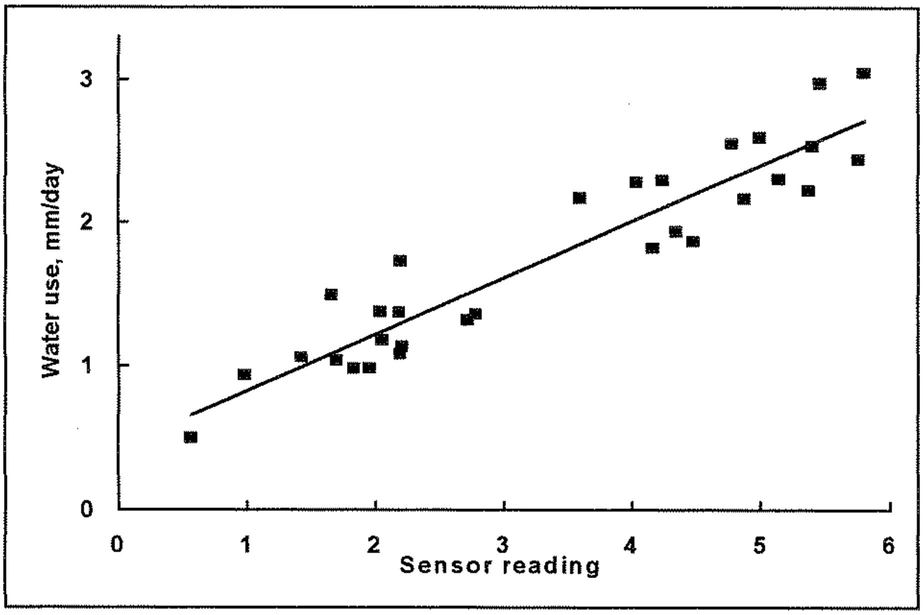

Figure 8. Graph illustrating the close correlation between daily plant water use and evapo-sensor readings (experiment 2)

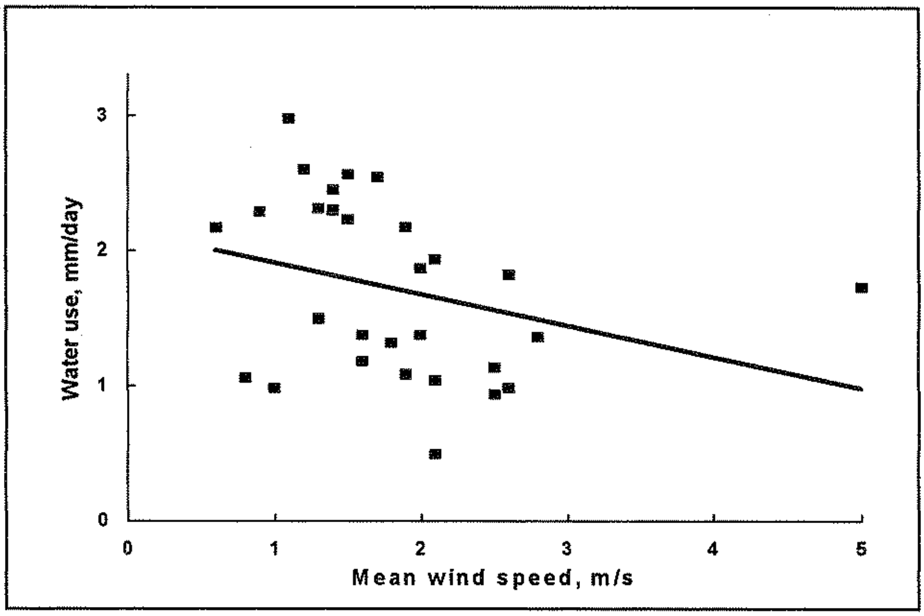

Figure 9. Graph illustrating the very weak, and in this case negative, correlation between daily plant water use and wind speed (experiment 2).

Correlation analysis is a statistical technique that quantifies the degree of scatter around a straight line in graphs such as these. It was used here to compare objectively the various estimates of water use. The results are presented in Table 2, expressed in terms of the percentage of variation accounted for. The larger the percentage accounted for, the more useful for estimating plant water use. The negative values shown for wind in experiment

2 indicates that, in that case, water use *decreased* as wind *increased*, confirming the weak link between water use and wind speed evident in Figure 9.

Table 2. Correlation of plant water use with different ways of estimating potential evapotranspiration.

Method	Variation accounted for, %			
	Experiment 1	Experiment 2	Experiment 3	**Mean[1]**
	Including all days for which data are available			
Evapo-sensor	88	87	87	**87**
Pan evaporimeter	83	87	83	**84**
Solar radiation	85	83	67	**78**
Leaf-model evaporimeter	88	72	69	**76**
Penman	76	64	76	**72**
Bucket evaporimeter	56	92	56	**67**
Mean air temperature	61	52	12	**38**
Mean wind speed	22	8 (-ve)[2]	45	**8**
	Excluding days when it rained			
Evapo-sensor	88	87	88	**88**
Pan evaporimeter	76	90	71	**79**
Solar radiation	85	77	79	**80**
Leaf-model evaporimeter	88	69	69	**75**
Penman	76	66	83	**75**
Bucket evaporimeter	92	94	85	**90**
Mean air temperature	69	59	10	**41**
Mean wind speed	21	27	56	**5**

[1] Calculated as the square of the mean correlation coefficient

[2] (-ve) indicates a negative correlation

Figure 10 shows that the evapo-sensor was the most closely correlated while the data in Table 2 show that it was also the most consistent, always accounting for 86 to 88% of the variation. The evapo-sensor, which is strongly sensitive to radiation level, consistently outperformed radiation alone. This remained true even in experiment 3, in which it was also compared with an additional light sensor integrated over exactly the same periods. This suggests that the *additional* sensitivity of the evapo-sensor to humidity, temperature, and wind was a real advantage.

Some of the more conventional methods, such as the pan evaporimeter, also look feasible. The 'bucket evaporimeter', intended as a more user-friendly method based on the same principle, also worked well except on rainy days (Fig. 10).

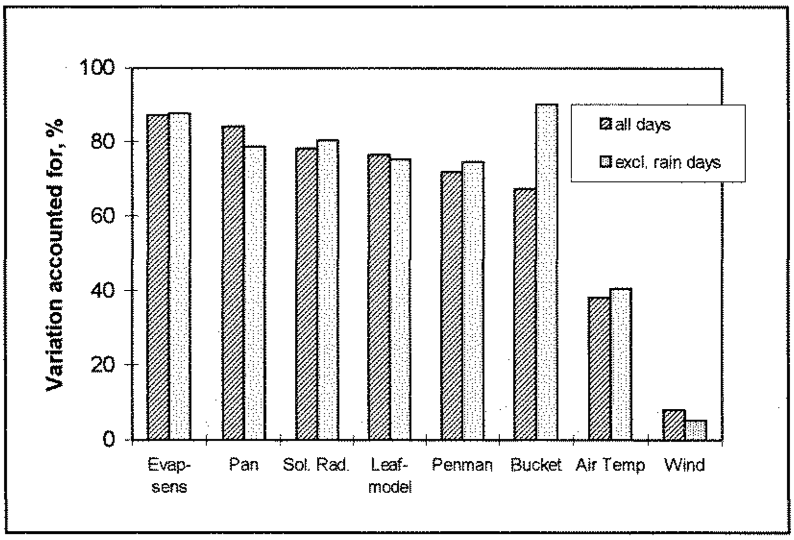

Figure 10. Comparison of alternative methods of estimating water use by well-watered plants (means of all experiments).

Differences between subjects

Figure 11 shows how the average rate of water use over the course of experiment 1 differed between species, and between plants of different size within the same species. Where two sizes were present, the large plant always used more water, despite spacing being adjusted to suit the size of plants. However, there was remarkably little variation between plants of extremely different habit (for example the tall and feathery *Leptospermum* compared to the squat and dense *Juniperus*). It should be remembered that the data are expressed per unit area of land; on a per plant basis, the large *Leptospermum* was using about 7 times more water than the small *Juniperus* (245 v. 36 cm^3/day). Of considerable practical importance is the water use per unit surface area of the pot, because that is the area available to intercept sprinkler irrigation. On this basis the difference between small plants in close-spaced pots (e.g the small *Juniperus*) and large, well-spaced plants (e.g. the large *Leptospermum*) was much larger (Fig. 12).

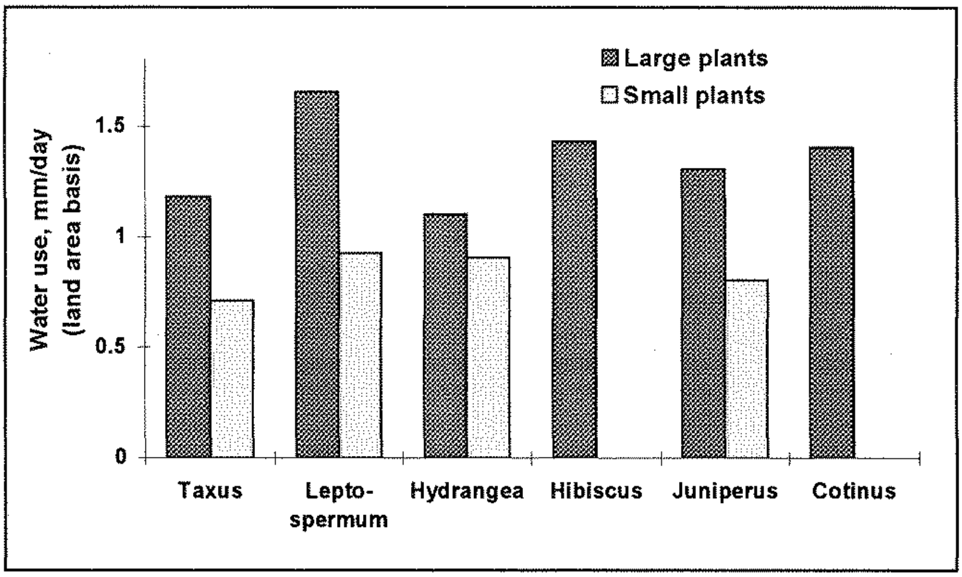

Figure 11. Comparison of water use by different subjects. Data are average values from 1993, expressed **per unit area of land.**

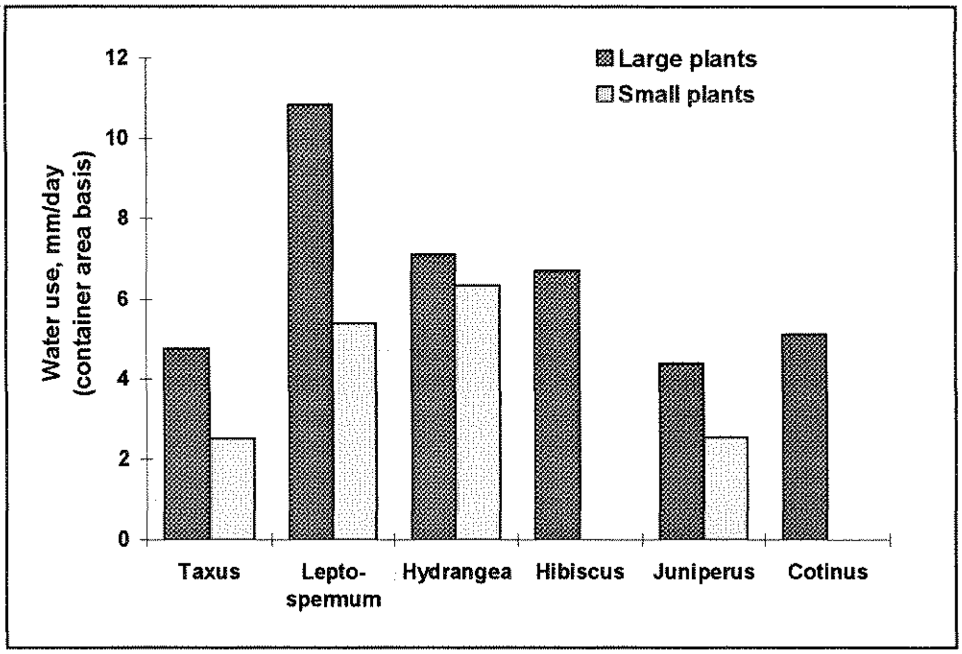

Figure 12. Comparison of water use by different subjects. Data are average values from 1993, expressed **per unit area of the open surface of the containers.**

Figure 13 shows that conifers and broad-leaved species responded very similarly to the day to day changes in weather. The same was true of different species within each group.

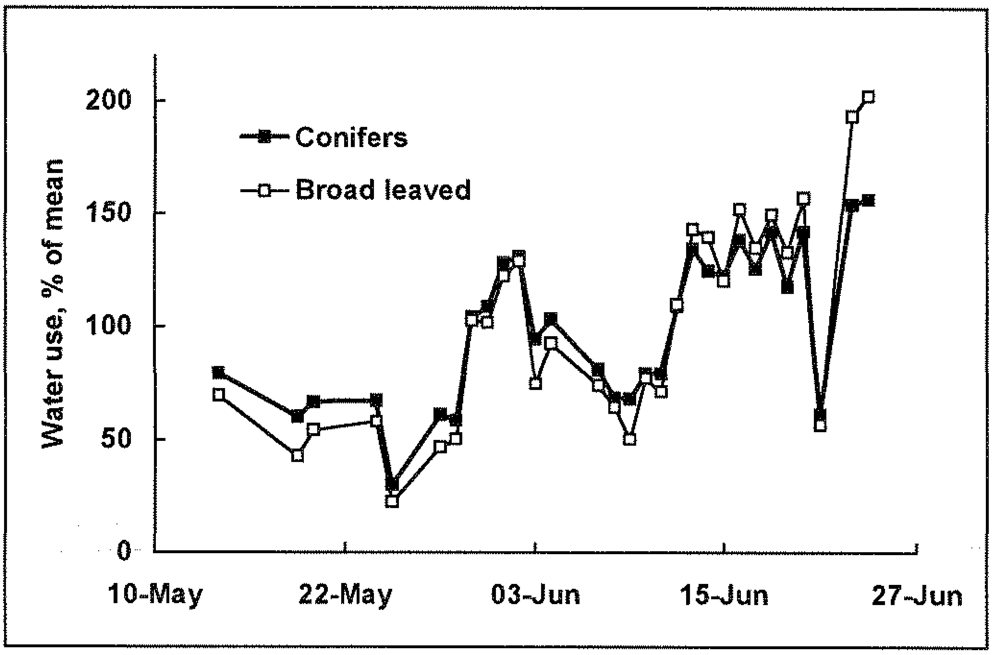

Figure 13. Close parallel of variation in water use in different types of plants. Data are expressed as percentage of the mean for each type

Edge-of-bed effect

Being more exposed to wind and solar radiation, it is reasonable to expect plants at the edge of a block to use more water that those in the centre, particularly if the adjacent ground is dry. The results from experiments 1 and 2 confirmed this but also showed that the effect was rather small, plants at the edge of the bed using on average only 8% more than other plants (Table 3). The inconsistencies evident in the table suggest that variation between individual plants of the same subject was of the same order as the edge effect.

A similar conclusion emerges from experiment 4, in which water use was monitored from the first to the sixth row of a pot-thick stand of *Forsythia* x *intermedia* 'Lynwood'. Plants were about 100 cm tall, and appeared very uniform but Figure 14 shows that the edge effect was still of the same order as the plant-to-plant variation. The effect was statistically significant ($P < 0.001$), and appeared to penetrate to the second row at least.

Table 3. Percentage increase in water use by plants at the edge of the bed.

Subject		Experiment 1	Experiment 2
Taxus	- large	13.9	-3.4
	- small	7.3	10.1
Leptospermum	- large	8.1	no data
	- small	2.3	no data
Hydrangea	- large	14.6	-5.1
	- small	-21.0	-11.0
Juniperus	- large	30.6	26.6
	- small	no data	10.4
Cotinus	- large	19.5	18.4
Mean of all subjects		**9.4**	**6.6**

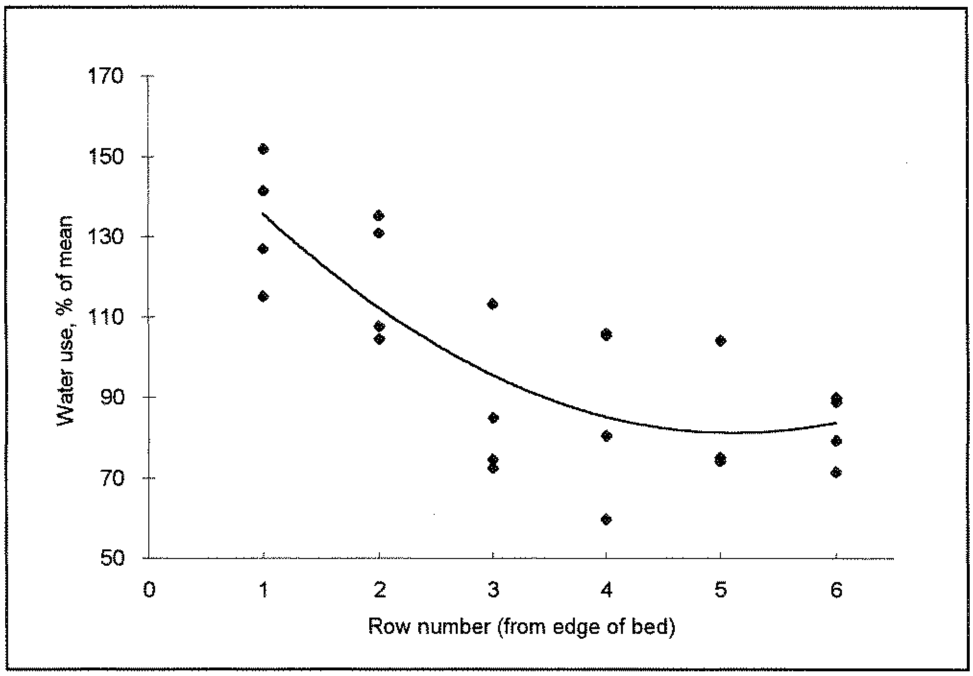

Figure 14. Edge-effect on water use by *Forsythia* at pot-thick spacing. Plotted values relate to individual plants and the scatter indicates substantial plant to plant variation.

Effect of spacing

This was also examined using *Forsythia* in experiment 4. The results in Table 4 showed that the amount of water used by each plant went down when they were grown at close spacing. However, while the number of plants per unit area was increased 4 times, the amount of water used by each plant decreased by less than half, so that the water use per square metre increased by about 2.5 times (equivalent to an extra 150%).

Table 4. Effect of spacing on water use by *Forsythia* in 2 litre containers

Spacing	Water use	
	per plant , g	per unit area, kg/m^2 (= mm)
35 x 35 cm	302	2.46
17.5 x 17.5 cm	186	6.08

The data were collected 3 weeks after spacing treatments were applied, all plants having previously been pot-thick. The wide spaced plants were already visibly more vigorous as a result, but exchanging the plants between treatments showed that this had relatively little influence on the rate of water use.

Effect of standing surface

As spacing is increased, and more solar radiation reaches the ground, the nature of the standing surface is likely to affect the temperature and humidity around the plants and therefore their water use. For most of the experiments described in this report, the standing surface was the moist sand of a capillary bed. Experiment 5 measured the effect on water use by *Forsythia* of covering the sand with Mypex. The plants were wide-spaced (35 x 35 cm), allowing about 15% of solar radiation to reach the ground. Standing plants on Mypex increased water use, but by only 3.3%.

Effect of 'lean' watering

Experiment 6 examined the effect on both water use and growth of not providing as much water as the plant was capable of using (i.e less than its ET_p). In the control treatment, water was applied every day to replace what had been used in the previous 24 hours, the amount applied being taken as the ET_p for the other treatments. The other plants then received either three quarters or half this amount according to treatment (0.75 ET_p and 0.5 ET_p treatments respectively).

After 3 days, water use by plants in the 0.5 ET_p treatment had fallen to half that of the well-watered control plants so that they were then using water at the same rate as it was being applied. As a result, the water content of the medium stabilised around a new value, which was well below container capacity. The dryness of the medium was evident as shrinkage from the sides of the container, but on only one occasion was wilting seen, and then only slight wilt of the youngest leaves for a short time on a very sunny day. Since the experiment was started in late August, shoot growth was slowing down even in the control plants so that the experiment was not a sensitive test of effects on growth. However shoots in the 0.5 ET_p treatment continued to elongate for 6 days after the treatment was started.

Results for the 0.75 ET_p treatment were similar to the 0.5 ET_p except that it took 10 days before water use had reduced to match the amount of water applied.

For 5 days at the end of the experiment, tensiometers were installed which indicated an average tension before irrigation of 248 and 324 millibar in the 0.75 and 0.5 ET_p treatments respectively. Physiological measurements on the leaves showed that stomata were more closed in the lean-watered plants, limiting water loss and thus preventing serious desiccation (leaf water potentials were all in the range from -0.73 to -1.02 MPa).

Discussion and conclusions

To assess the feasibility and likely benefits of regulating irrigation of containers according to daily estimates of potential evapotranspiration, this project addressed four questions:

- How much does potential evapotranspiration (ET_p) from HNS in containers vary from day to day?
- Is there a simple physical measurement from which ET_p can be estimated accurately enough to be useful for irrigation management?
- How important are other sources of variation in irrigation requirement?
- How do plants adapt to lean watering, i.e. to receiving consistently slightly less water than they are capable of using?

The structure of the following discussion relates to these questions.

Day to day variation in evapotranspiration

In both the major experiments, the amount of water used by the experimental plants fluctuates up to 6-fold between days, and up to 3.5 times between consecutive days (Figs 6 and 7).

From this it is clear that the widespread use of timers to open irrigation valves for a set period every day is likely to be highly inefficient. Furthermore, adjustments to allow for natural rainfall are **additional** to the variation identified here.

The water storage capacity of the growing medium provides a buffer that helps even out the fluctuations in irrigation requirement but the volume of a container is too small to rely heavily on this. Plants spaced at 35 x 35 cm, using water at 2mm/day, consume 245 cm^3 of water in a day, more than half the readily available water in a 2 litre container of a typical medium.

Methods of estimating potential evapotranspiration

The results of experiments 1 to 3 clearly show that a number of physical methods of estimating potential evapotranspiration correlated well with actual water use by well-watered plants in containers (Fig. 10). Close correlations were observed in all three experiments despite differences in season and subjects used.

The most consistent correlation was with the evapo-sensor, despite it being originally designed for use in propagation environments, where its ability to respond to leaf wetting was crucial. Its strength is that it also responds to all other factors that influence evaporation, including humidity, temperature and radiation level. Radiation level alone was able to account for much of the variation in evapotranspiration (77%), but the multi-factor sensitivity of the evapo-sensor accounted for an additional 9% on average.

Since the evapo-sensor is electrical, it could easily be incorporated into an automatic irrigation control system. However, in the first instance, it is probably more realistic to envisage it connected to an electronic counter, totalling units of potential evaporation over the course of the day, the grower then making use of this count when deciding on whether to irrigate and for how long. Experience gained using it in this way would then guide the development of automatic systems.

The pan evaporimeter was the next best correlated measurement but it is not one that growers would be likely to undertake for themselves. It consists of a large shallow tank of water and involves the use of a rather tricky depth gauge to measure the water lost by evaporation.

A simpler alternative, referred to as a "bucket evaporimeter", was devised for this project. Here the tank is replaced by a plastic bucket so that evaporation can be monitored by weighing or, if no suitable balance is available, by pouring the water into a measuring cylinder. The correlation with plant water use was not as good as for the pan evaporimeter unless days when it rained were excluded. This suggests that the amount of rainfall intercepted by the bucket did not match that collected by the rain gauge, probably due to wind eddying around the large bucket and/or surrounding obstructions. A shallower vessel, with vertical sides and narrow lip, sited immediately adjacent to the rain gauge, would probably avoid this problem. A large paint kettle, cut down to a height of about 15cm, might be suitable.

The reasonably close correlation with solar radiation is of interest because this is another method that lends itself to automation. Solar radiation is already widely used to control irrigation of glasshouse crops such as tomatoes, but it is less likely to be satisfactory outdoors where other factors, such as humidity and wind speed, are more variable.

Wind speed alone accounted for very little variation, indeed in one case the correlation was negative, indicating that the *greatest* water use tended to occur on the *least* windy days.

Other sources of variation

The correlation data relate to the *average* water use of many species. Whether any ET_p estimate proves a satisfactory basis for irrigation control depends largely on the variation contained within those averages, that is to sources of variation other than the weather. Experiments 1 to 3 addressed what is arguably the most important of these, variation between different species and sizes of plants.

Species and size

Considering the range of plants involved, the variation was quite small once the effect of size was reduced by expressing the data per unit area, rather than per plant (Figure 13). However, even then, larger plants consistently used somewhat more water than smaller ones of the same species. This probably reflects that fact that spacing of the larger plants is based on the lateral spread of the branches whereas the area of foliage is also increasing vertically. However, on a commercial scale with large blocks of similar plants, vertical size of plants would tend to have less effect than in the small scale experiments used here.

There was no clear separation between plant types, neither between conifer and broad-leaved nor between wilt-prone *Hydrangea* and less wilty *Cotinus*. Furthermore, the weather influenced the different types in a very similar way (e.g. Figure 13).

Spacing and standing substrate

Spacing emerged as the most important factor to be taken into account when relating the amount of irrigation to be applied to any ET_p estimate. In an experiment with *Forsythia*, well-spaced plants used more water per plant, but this was not enough to prevent water use per unit area decreasing by 60%. The implications for irrigation requirement, which depend on both the method of application and the substrate the containers are standing on, are discussed below.

For overhead irrigated plants standing on Mypex, gravel, or other non-capillary material, only the water which falls directly into the container will reach the plants. For every millimetre of irrigation applied, the amount of water intercepted is determined by the area of the upper surface of the container, irrespective of spacing. Therefore, when plants are spaced out, not only does a larger area require irrigation, but the rate of application has to be increased in line with water use per plant. Even for a pot-thick stand, the gaps between circular containers lead inevitably to 22% of overhead irrigation missing its target, but this wastage escalates as they are spaced out.

On the other hand, with drip irrigation, all the water applied is available to the plant so that the amount required simply needs to be increased in line with the increased water use per plant. This reflects the inherently higher precision of drip irrigation. The additional benefit of being able to apply nutrients with similar precision helps to offset the high cost of drip systems.

Placing plants on a sandbed also inherently increases efficiency of water use. Water falling between the containers can then also reach the plants via the sand. In this case, when plants are spaced out, irrigation requirement might decrease in line with water use per unit area of land, though some allowance would have to be made for evaporation from the sand itself so that, in practice, the irrigation requirement would be virtually unchanged. The same would apply to plants irrigated entirely by capillarity using a seep-hose irrigated sandbed.

Edge effect

By contrast with spacing effects, the nature of the surface on which the plants were standing had little effect of water use per plant. Similarly, the increase in water use of plants at or near the edge of a bed was rather modest, suggesting that the main reason why supplementary watering is often needed at the edge of beds has more to do with uneven distribution from sprinkler systems than with additional evaporation from plants around the edge.

Response to 'lean' watering

Because no irrigation systems can apply water perfectly evenly, and there are many factors causing some individual plants to use more water than others, any attempt to match irrigation to the ET_p of the *average* plant is bound to result in some *individual* plants receiving less than their ET_p. What is more, ET_p is likely to include a degree of 'luxury consumption' and providing enough water to meet ET_p may tend to produce plants which grow rapidly but whose quality suffers from being unnaturally soft. There may therefore be real advantages in intentionally applying slightly less than ET_p.

The small experiment with *Forsythia* (experiment 6) demonstrated how plants are likely to respond to consistently receiving less than they are *capable* of losing. Initially they continued to lose water at the same rate (i.e. at ET_p), but since part of this was not being replenished, the medium became progressively drier. This did not continue indefinitely because the plants adapted to the shortage of water by partial closure of the stomata, thereby reducing their rate of water loss. Eventually, water loss came to balance water supply, with the medium substantially drier and the plant held under a roughly stable degree of stress. Physiological measurements showed that, in the case of *Forsythia*, adaptation was fully effective in preventing damaging desiccation. On the other hand, it involved partial closure of stomata which would tend to reduce photosynthesis and thus might reduce growth rate.

Amongst a variable set of plants, carefully regulated and uniform irrigation could help to reduce variability. If the amount applied was matched to the average ET_p of the set, then it would be less than the greater ET_p of the larger plants, whose growth would thus be slightly reduced, helping to produce a more uniform plant quality. This is the opposite of what happens when plants are growing together in soil, competing for their share of the *same* reservoir of water.

Further studies, with a range of species and over a whole season, will be needed to properly evaluate the opportunity to save water and/or increase quality by regulating irrigation in this way. However, the results of this preliminary experiment are encouraging.

Practical conclusions

In summary, the practical conclusions of this study are as follows:

1. Variations in water use from day to day are too large to ignore: a fixed irrigation period every day is likely to be very wasteful.

2. There are a number of ways that water use can be estimated accurately enough to be useful. Of these the evapo-sensor looks most promising but is still in the process of being commercially developed. The simplest is the "bucket evaporimeter" which performed well except when there was measurable rainfall. A simple modification will probably overcome this difficulty and could be tested immediately by interested growers.

3. Variation in water use between plants of different size and species is also too large to ignore. The range of plants within each irrigation area should therefore be minimised.

4. Overhead irrigation is particularly inefficient when containers are spaced out. Standing plants on a sandbed reduces this inefficiency. Drip irrigation is also inherently more efficient and should be considered, especially for larger plants.

5. When plants consistently receive less water than their ET_p, they adapt to reduce their transpiration so as to avoid serious desiccation. It is likely that in some species this adaptation does not substantially reduce growth and may in some cases improve quality.

Glossary

Evapotranspiration - the amount of water lost by evaporation direct from the soil (or the medium in the case of containers) combined with that evaporating from the plant as transpiration. 'Plant water use' is used synonymously in this report.

ET - abbreviation for evapotranspiration

ET_p - abbreviation for potential evapotranspiration.

Potential evapotranspiration - evapotranspiration from a plant well-supplied with water so that shortage of water does not limit either transpiration through the plant, or evaporation from the soil/medium.

Stomata - the pores in the outer layers of the leaf through which gas exchange takes place with the air around it. The size of the pore orifice varies in response to factors such as light and water stress, and in this way exercises some control on transpiration rate. **Stomatal conductance** provides an indirect measure of the size of the pores.

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References

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Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for research/development project.

PROPOSAL

1. TITLE OF PROJECT

Contract No: HNS38a
Contract date: 2.6.93

ESTIMATING IRRIGATION NEEDS FOR HNS IN CONTAINERS

2. **BACKGROUND AND COMMERCIAL OBJECTIVE**

The combination of a series of dry summers and the increasing attention being paid to pollution control have focused attention on ways of increasing the efficiency with which plants in containers are irrigated. To some extent capillary sand beds provide a way of automatically regulating water in line with the needs of the crop. However, the capital cost of installing capillary beds is roughly three times that of an overhead system and it is therefore unrealistic to see capillary beds as an immediate answer whilst new investment is severely restricted by the recession. There is therefore an urgent need to investigate ways of reducing wastage of water by the efficient use of the existing irrigation systems, ie overhead sprinklers with a gravel and/or Mypex base. Anecdotal evidence suggests that the current, largely intuitive, methods of regulating the amounts of water to be applied generally results in overwatering because the results of under-watering are much more visible than those of over-watering. The current proposal will test a number of ways of measuring "evaporative demand" (technically the potential evapotranspiration) and identify those which might be suitable for estimating the irrigation requirement of plants in containers on a day to day basis.

3. **POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY**

The direct benefit of a successful means of estimating the minimum amount of irrigation required is likely to be, at very least, a 10% reduction of water bills. There are also likely to be indirect benefits in terms of reduced fertiliser requirements because of reduced leaching, and improved quality through avoidance of overwatering. Furthermore, by adopting improved methods of irrigation regulation, the industry would be seen to be taking a responsible attitude to the pollution issue and therefore less likely to find itself forced to convert to more capital intensive systems such as capillary sand beds.

4. **SCIENTIFIC/TECHNICAL TARGET OF THE WORK**

There already exist means of estimating evapotranspiration from large areas of uniform field crops such as cereals, and from protected crops such as tomato. These are either based on mathematical relations to various aspects of weather, or on simple instruments such as the pan evaporimeter. Any one of these might correlate sufficiently closely with the actual water use of HNS on container beds to be useful for estimating the irrigation requirement. The proposed work would test for such correlations using a range of different species and sizes of plant. Whilst it is anticipated that one method will be applicable to all plants, a number of alternative calibration factors are likely to be needed to allow for the effect of plant type and stage of growth. It may also be possible to examine the effect of other factors, such as plant spacing, which could effect calibration factor. In the long term, there is need for much more understanding about how much the water supply can be restricted before growth and/or quality are significantly affected. That is a very difficult area to research and is beyond the scope of the present proposal.

5. CLOSELY RELATED WORK COMPLETED OR IN PROGRESS

This proposal stems directly from experiments in HNS28 at East Malling in which controlled water stress treatments were successfully created by limiting irrigation to a fixed proportion of the potential evapotranspiration. In that case, the system was being used as an experimental tool and drip irrigation was employed, but the ability to bring about a modest restriction of growth without plants ever being seen to wilt was impressive.

There is also a close link with the associated proposal, HNS 38 at Efford, examining cost-effective improvement in water use efficiency of overhead systems by changes in the substrate, particularly addition of sand to existing gravel bases. To benefit from such improvements, careful regulation of the amount of water applied will be essential because the water holding capacity of a thin sand layer is small and once exceeded extra water will drain to waste.

There is also strategic work on methods of estimating evapotranspiration in the propagation context in L102A. That relates to the need to optimise the control of water applied to cuttings, as mist or fog. The evapometric sensor/controller being developed in that programme will be included amongst the methods of estimating evaporative demand to be tested in this project.

6. DESCRIPTION OF THE WORK

Three stages are envisaged as follows:

(i) Assess possible methods of estimating potential evapotranspiration (E_o) for inclusion in the trial. Decisions will be based on cost, convenience of use (including possibilities of automation), and expected accuracy. Consideration will be given to inclusion of methods that relate to actual evapotranspiration

(E) from plants, such as a tensiometer to measure the dryness of the medium.

(ii) Set up trial with 3 types of plants at 2 stages of growth (industry co-ordinator to advise) under overhead irrigation on Mypex. The change in weight of the plants and their containers will provide measurements of E between irrigations. Instruments to estimate E_o will be set up in an adjacent area and will be read at the same intervals.

(iii) Analyze the data statistically to determine how closely the various estimates of E_o correlate with E and how the relationship differs between types and sizes of plants. It should be possible to make preliminary assessments once 4 to 6 weeks of data have been accumulated, so that any problems in the methodology can be identified and rectified at an early stage. If all goes well, it would then be possible to alter the trial so as to incorporate additional factors (eg spacing, substrate or exposure).

7. COMMENCEMENT DATE AND DURATION

Start date 01.04.93; duration 1 year.

It is anticipated that there may be follow-up projects, perhaps examining the effect on plant growth and quality of alternative "irriguides" developed in the first year.

8. STAFF RESPONSIBILITIES

Project Leader: Dr R S Harrison-Murray
Other staff: R Cameron

9. LOCATION

HRI - East Malling