The use of tensiometers to control the irrigation of nursery stock in containers

Project 4460

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Summary

The use of digital tensiometers to control the irrigation of nursery stock in containers was studied over a three year period. Over this time the tensiometers performed satisfactorily and successfully automated the irrigation of the plants. The results indicate the feasibility of using them to control nursery stock irrigation under Irish conditions.

An irrigation tension of 50 hPa to trigger an irrigation period resulted in larger plants than those grown under drier regimes with irrigation tensions of 100 and 200 hPa. Measurements of stomatal resistance indicated that the plants in the drier regimes were growing under greater moisture stress.

The drier regimes reduced the number of irrigations and also the overall usage of water. They reduced plant size but did not impair plant appearance. It may be possible to use this approach in the future to control plant growth.

There was no difference in performance between plants gown with ebb and flood irrigation and those irrigated via overhead spraylines. The ebb and flood system gave a considerable reduction in water use.

Introduction

Nursery stock plants are commonly grown, in a peat based growing medium, in containers with a volume of 2 litres or less. In this system there is only a relatively small reservoir of water available to them which makes some form of irrigation a necessity. On most nurseries, this is provided by a system of overhead sprinklers which is usually turned on manually when an irrigation is judged to be necessary. Where the system is automated a timer is used, so the grower has to anticipate weather conditions and set the controls accordingly. The results depend on the grower's skill and attention to detail. It was felt desirable to study the use of a fully automated system which would reduce the need for grower intervention in deciding when irrigation was required.

There are two approaches which can be used to do this. One is direct measurement where some type of sensor is used to measure the moisture status of the growing medium and sends a signal which controls the irrigation system. The other method is indirect where the water use of the crop is calculated using a mathematical model of evaporation with the input of climate data such as solar radiation, temperature, wind speed and humidity. A crop factor depending on the crop type and stage of development will also have to be included in the model. This approach requires the use of a weather station and computer.

It was decided to use the direct measurement approach at Kinsealy and digital tensiometers were selected as the moisture status sensor. The tensiometers consisted of a glass tube, with a ceramic cell at the bottom, which is partially filled with water and then closed on top. The ceramic end is placed in the growing medium. As the medium dries out when the plant takes up water, the water in the tube tends to diffuse through the ceramic tip into the medium creating a partial vacuum in the tube. A pressure switch on the tube senses this and sends an electric signal to an irrigation controller at a pre-set tension. Digital tensiometers were used because they were relatively inexpensive and because the digital signal needed no amplification over long distances of cable between the sensor and the controller.

Methods

Growing system

Eighteen growing beds each measuring 5 x 1.8 m and each plumbed back to its individual reservoir were used for the experiments. Drainage from the beds flowed back to the reservoir and was re-cycled. Each bed therefore constituted an individual closed re-cycling system. The beds had wooden sides, were lined with butyl rubber and had a 5 cm deep layer of pea sized granite gravel covered with mypex cloth. A drainage pipe ran lengthways along the centre of the bed.

Nine of the beds received ebb and flood irrigation. Water was supplied by a submersible pump in the reservoir through a perforated pipe in the gravel layer at one side of the bed. Pumping continued until the level of the water was 3 cm above the mypex. The pump was then turned off. After a further six minutes a solenoid valve in the return pipe opened and the water in the bed drained back to the reservoir. The length of the flooding period was decided on the basis of water uptake experiments.

The other nine beds were irrigated using overhead spray lines. These were placed at the sides of the beds and the spray was directed inwards through 180 degree throw nozzles. A spray line irrigation period lasted five minutes.

Irrigation control system

A tensiometer was placed in a single 2-litre pot in each of the eighteen growing beds. The tensiometers used were TSA T tensio switches (made by WfB GmbH, Freising, Germany). They were 23 cm long with a ceramic cell length of 3 cm. The pots were 13 cm high and the tensiometer was placed so that the middle of the ceramic cell was 4 cm above the bottom of the pot. Six of the tensiometers were set to operate at a tension of –50 hPa (hectoPascals), six at –100 hPa and six at –200 hPa.

The tensiometers were connected to the serial port of a PC via a digital input/output (I/O) module (MINI-KLIWADU system supplied by Georg F. Shreinzer Positronik, Freising, Germany). The control programme, written in Microsoft Visual Basic, tested the status of the tensiometers every minute and when irrigation was required operated relays, again through the I/O module, which in turn controlled the irrigation pumps and solenoid valves. All irrigation periods were logged in a database.

Cultural

Cuttings of *Viburnum tinus* were taken in December 1996 and rooted on a warm bench under plastic. The rooted cuttings were potted on into 2-litre pots and were laid out on the growing beds at 30 cm centres on June 1. The growing medium was Bord na Mona nursery stock grade peat with the addition of dolomitic lime at 4 kg/m^3 and a controlled release fertiliser (Osmocote 12-14 month) at 5 kg/m^3. The tensiometers controlled the irrigation of the experimental plots from then until the end of September. At intervals plants were taken from the plots and the fresh weight determined. These plants were replaced with similarly aged plants.

The plants were over-wintered in situ in the growing beds. In 1998, the tensiometers were placed in the pots on May 1 and controlled the irrigation until the end of September. At this stage half of the plants were harvested. The rest of the plants were over wintered in the beds. They were cut back before the experiment commenced in early May 1999. Throughout 1998 and 1999, the plants were irrigated with a nutrient solution containing macro and micro nutrients.

Young plants of *Hydrangea macrophylla* 'Bouquet Rose' were potted into 2-litre pots containing nursery stock grade peat with lime and a dressing of 1 kg/m^3 of PG mix, a compltet fertiliser. They were placed in the beds in May, 1999 and occupied 50% of each growing bed. In this season the controlling tensiometers were placed in a pot containing a *Hydrangea* as it was felt that this fast growing plant would be most limited by water supply. The experiment was terminated at the end of September 1999.

Monitoring tensiometers

As the PC was logging all irrigations the behaviour of the tensiometers, in terms of the number of times irrigations were being called for, could be easily monitored. However because the digital tensiometers only gave a +/- signal there was no record of the moisture status of the peat on a continuous basis. This was provided using six time domain reflectometry (TDR) sensors which measured the volumetric water content of the peat. The six sensors were connected through a control box to a portable PC which took readings from the sensors every five minutes. The TDR sensors were calibrated using peat with measured water contents on a sand table.

Stomatal resistance

Beginning in 1998 but especially in 1999 measurements of stomatal resistance were made using a porometer type A4 from Delta-T Devices. A major response to water stress in plants is a reduction in stomatal aperture which has the effect of reducing water loss by increasing resistance to diffusion through the stomata. The porometer measures this. A small chamber, containing a humidity sensor, is clipped to the leaf and dried to a known humidity. The rate of increase of the humidity as water vapour diffuses from inside the leaf through the stomata into the chamber is then measured and the resistance of the stomata to diffusion calculated.

If the drier moisture irrigation regimes imposed in this experiment are affecting the plants by increasing moisture stress then this should be detected by the porometer. During the 1999 season regular measurements were made on the plants at different times of the day. To make one estimate, 10 individual measurements were made on leaves at a similar stage of development.

Results

Length of irrigation period

A number of experiments were carried out to determine how quickly water was taken up by the peat under both systems.. Pots (2-litre) were filled with nursery stock grade peat to a constant weight and were placed in ebb and flood beds which were flooded with a water to a depth of 3 cm. At intervals pots were removed and weighed so that the rate of water uptake

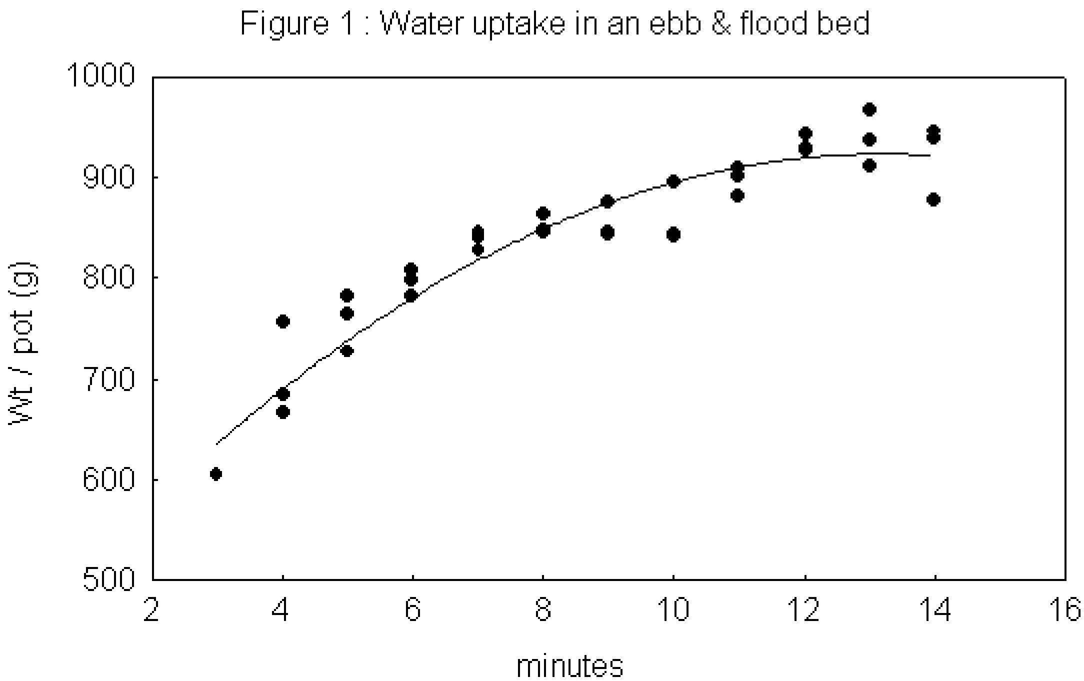

Figure 1: Water uptake in an ebb & flood bed

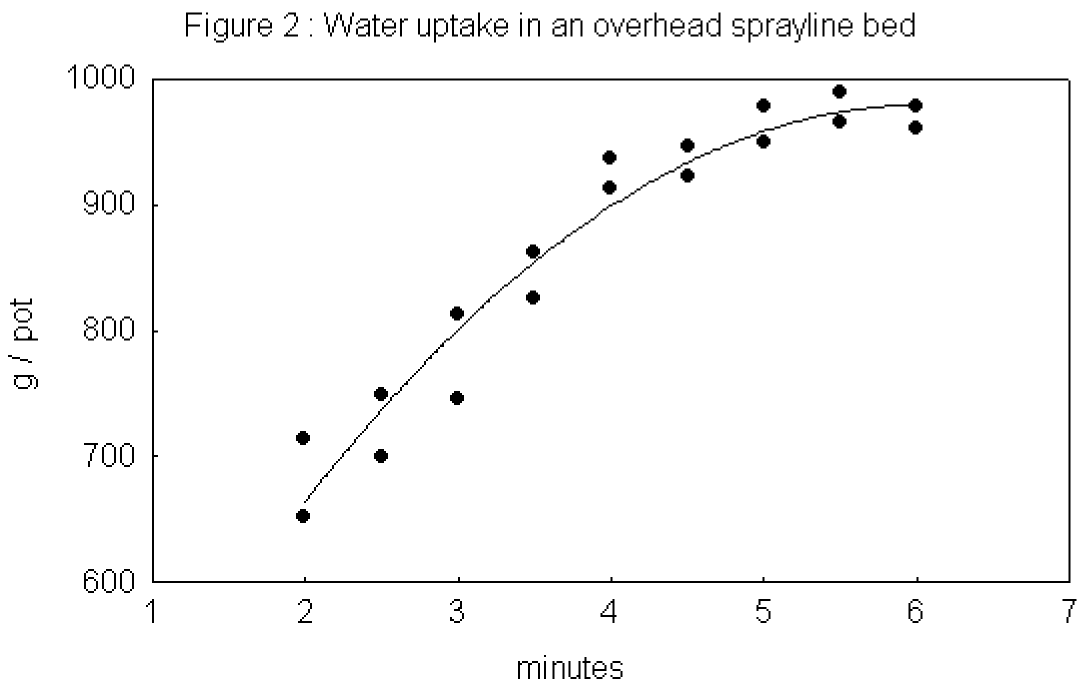

Figure 2: Water uptake in an overhead sprayline bed

could be estimated. It took about 10 to 12 minutes to bring the peat to container capacity (Figure 1).

Measurement of the precipitation rate under the overhead spray lines using glass cylinders indicated a rate of 2.6 litres m^{-2} $minute^{-1}$. Pots placed on the overhead spray line beds reached container capacity after about 5 minutes (Figure 2). On the basis of these results the lengths of irrigation period as described above were decided upon. The initial moisture content of the peat in these tests was 30% by volume. This was below the moisture content at which irrigation would be triggered even in the driest regime in this experiment. So under all three irrigation tensions, an irrigation period would restore the growing medium to container capacity.

Number of irrigations

The effect of the irrigation tension on the frequency of watering is shown in Figure 3. As the tension was increased from 50 hPa to 200 hPa so the number of waterings reduced from 30 to 10 in 1997, from 54 to 21 in 1998 and from 69 to 36 in 1999. The 100 hPa tension treatment was intermediate in all years. The smaller number of irrigations in 1997 is explained by the shorter season in that year and by the small size of the plants.

There was no difference in terms of the number of irrigations applied between the two irrigation systems in any of the three years.

Water usage

During the 1998 season the irrigation water usage of each plot was recorded by monitoring the volume of the water in the reservoirs on a regular basis. The results of this are shown in Figure 4. Irrigation with overhead spray lines used a lot more water than did ebb and flood irrigation. Evaporation of water from the fine spray would be greater than from the surface of the flooding water in the bed. The difference was probably increased in this experiment due to the small size of the individual plots. Although the nozzles of the spray lines were directed inwards onto the bed, during windy conditions an amount of water would have been blown outside the bed and thus lost to the system. Nevertheless, where water is an expensive commodity the difference in water usage would be a factor in deciding upon an irrigation system. Water usage tended to reduce as the irrigation tension was increased and the number of irrigations consequently reduced. Differences between the tensions was not as great as that between the irrigation systems.

Water content of the growing medium

The tensiometers worked satisfactorily in controlling the moisture content of the growing medium over the length of the experiments. A trace of the TDR showing the water content in pots over a 10 day period in August 1998 at the three irrigation tensions sensors is shown in Figure 5. During this period there were six irrigations triggered at the -50 hPa tension and three at each of the higher tensions. At the –50 hPa tension irrigation is triggered at about 55% moisture content while this is about 50% for the –100 hPa and 45% at –200 hPa.

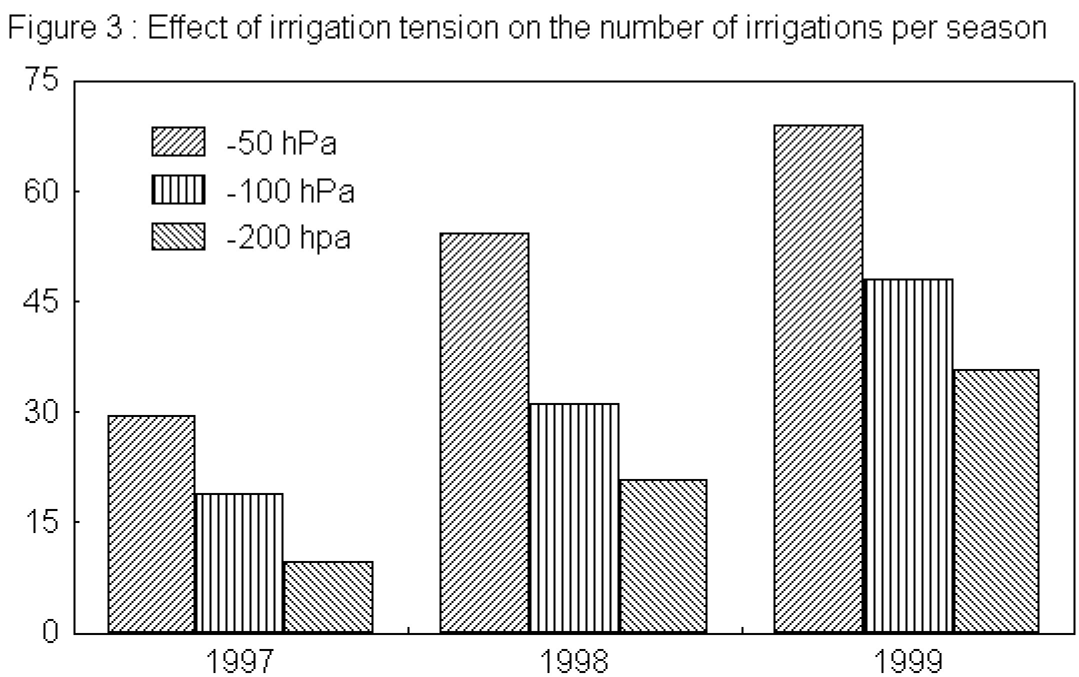

Figure 3: Effect of irrigation tension on the number of irrigations per season

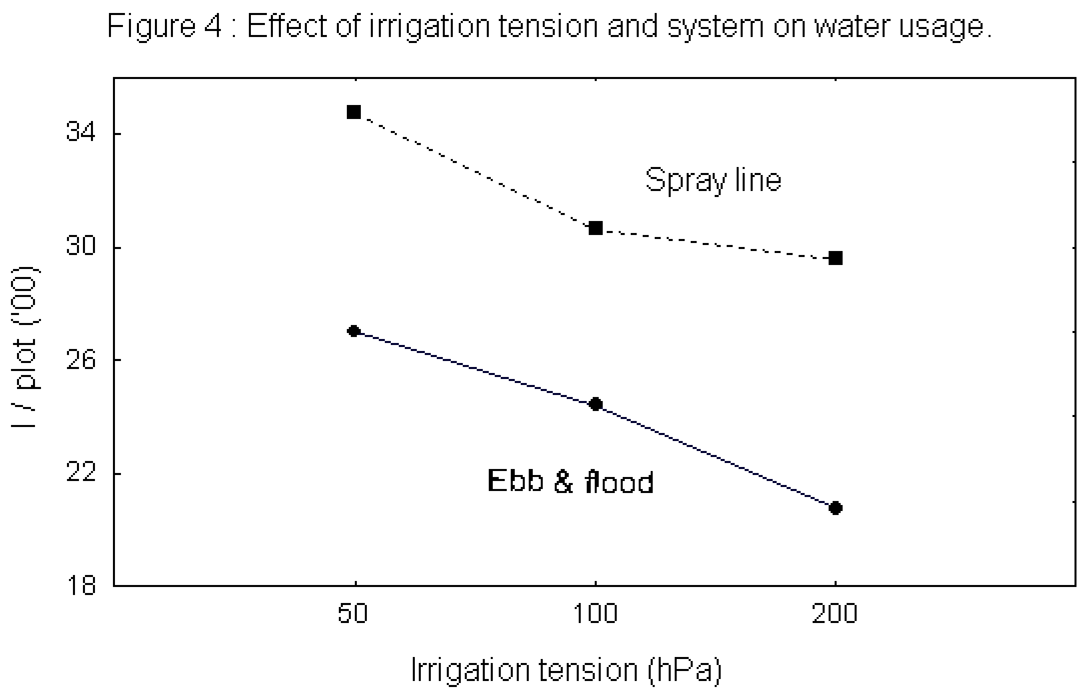

Figure 4: Effect of irrigation tension and system on water usage

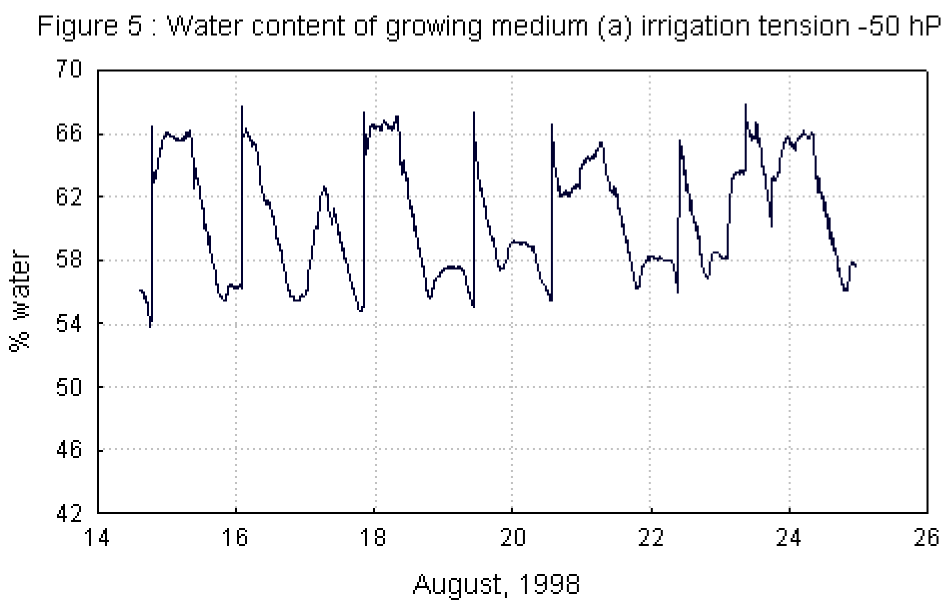

Figure 5: Water content of growing medium (a) irrigation tension –50hPa

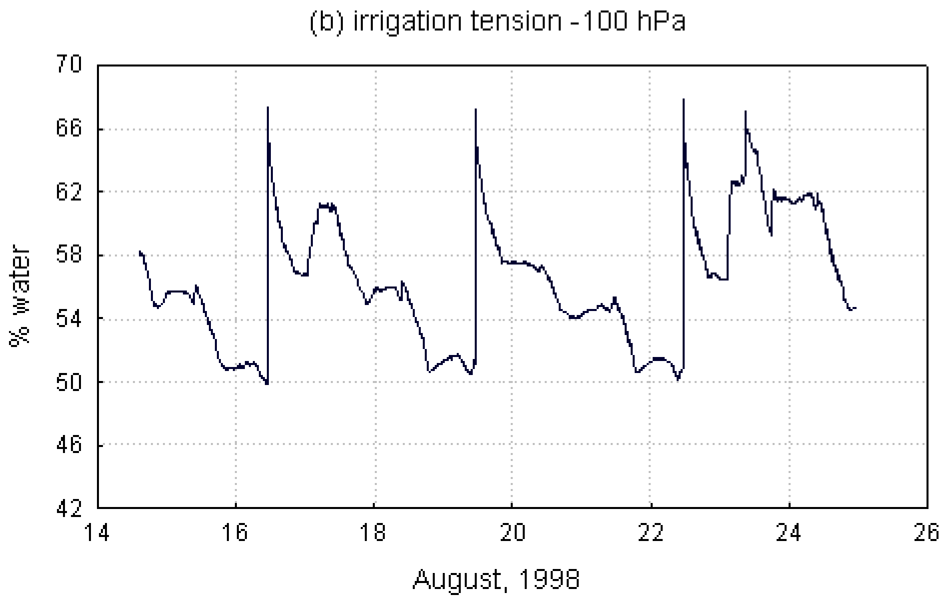

Figure 5: Water content of growing medium (b) irrigation tension –100hPa

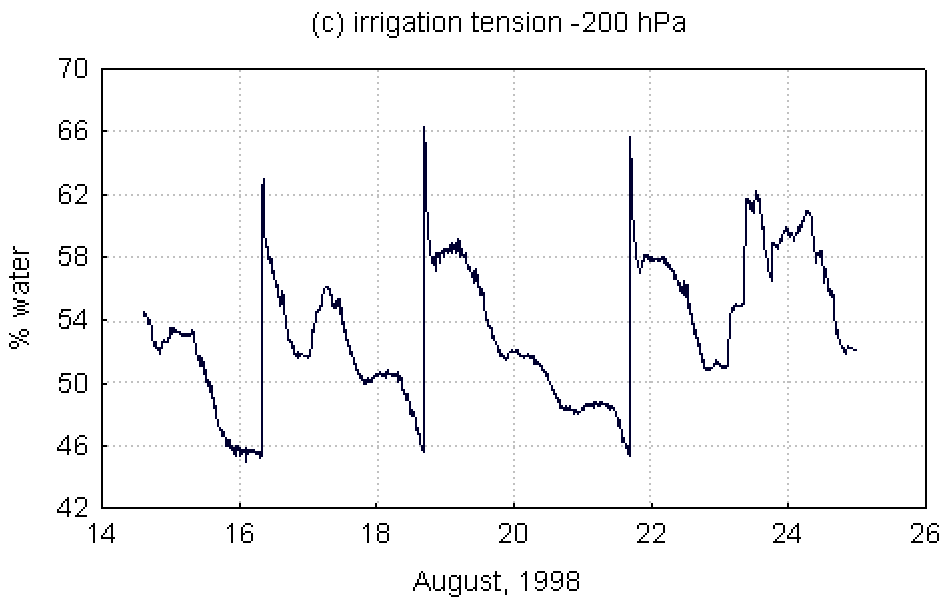

Figure 5: Water content of growing medium (c) irrigation tension –200hPa

Stomatal resistance

Correlation coefficients between stomatal resistance and the environmental parameters and the moisture content of the growing medium were calculated for the 1999 porometer data and are shown in Table 1.

Table 1 : Correlation coefficients between stomatal resistance measurements in 1999 and environmental parameters and water content of the growing medium.

Parameter	Viburnum tinus	Hydrangea macrophylla
Temperature	**0.29**	**0.34**
Light	**0.53**	**0.64**
Humidity	**-0.59**	**-0.47**
Water content	**-0.26**	**-0.27**

All the coefficients in Table 1 are statistically significant but those for light and humidity are higher than the others. The higher the light intensity and the lower the humidity, the greater the stomatal resistance. Resistance is negatively correlated with the water content i.e. as the moisture content in the growing medium declined stomatal resistance increased. However the potential evaporation as indicated by light intensity and humidity was the main determinant of stomatal resistance.

The stomatal resistance data collected for the three irrigation tensions were compared with each other on a paired comparison basis i.e. measurements made at the same time were compared with each other in order to eliminate climatic factors from the comparison. The results of this are shown in Table 2.

Table 2 : Effect of irrigation tension on stomatal resistance in 1999. In each column, values without a similar suffix are significantly different (p<0.05).

Irrigation tension (hPa)	Stomatal resistance (s/cm)	
	Viburnum tinus	***Hydrangea macrophylla***
-50	4.30[a]	3.69[a]
-100	5.04[b]	3.72[a]
-200	5.47[c]	4.01[b]

Each of these figures are means of 74 measurements. There was a clear response to irrigation tension in the resistance measurements made on *Viburnum tinus*. As the tension to irrigate was increased so too did the measured stomatal resistance over the season indicating that the plants were growing under greater water stress. The differences in stomatal resistance measured in *Hydrangea macrophylla* are not so large cut but the highest tension caused a significant increase in resistance again indicating an increase in water stress. In general, resistance values in *Hydrangea macrophylla* were lower than those in *Viburnum tinus.*

Plant growth

In the first season, there was no significant effects of irrigation tension on plant development (Table 3). At this time the plants were still small and the number of waterings was much less than in the next two years (Figure 3). So although the tension clearly affected the number of irrigations this was not sufficient to affect plant growth..

Table 3 : Effect of irrigation tension on the fresh weight (g/plant) of nursery stock.

Irrigation tension (hPa)	Viburnum tinus			Hydrangea
	1997	1998	1999	*macrophylla*
-50	25.2	174.3	238.6	341.5
-100	29.3	162.9	229.7	274.1
-200	26.2	151.5	207.8	237.2
F-test	NS	**	*	***
S.E. (df=10)	1.41	3.16	6.89	13.9

In the second year however the effect of irrigation tension became clear and increasing this above 50 hPa significantly reduced the fresh weight of *Viburnum tinus* plants. This trend continued in the third season when the controlling tensiometer in each plot was placed in a *Hydrangea* pot. The *Hydrangea* was more responsive to increasing irrigation tension giving over a 30% reduction in weight at the highest tension.

Table 4 : Effect of irrigation system on marketability and root score of *Viburnum tinus*, 1998.

System	Marketability	Root score
Ebb & Flood	6.22	5.93
Overhead spray	6.41	6.54
F-test	NS	**
s.e.	0.11	0.952

In the second season the *Viburnum tinus* plants were also scored for marketability which was a subjective assessment of the overall attractiveness of the plant and amount of healthy root visible in the root ball. Irrigation tension did not affect either of these characteristics but the overhead spray line irrigation gave a better root score than the ebb and flood system (Table 4). Particularly towards the bottom of the pots there was less root visible in plants from the flood beds. The appearance of the shoot as evidenced by the marketability score was not affected by the irrigation system.

Discussion

These experiments have demonstrated the feasibility of using tensiometers to control the irrigation of containerised nursery stock under Irish conditions. Over a three season period, the tensiometers functioned satisfactorily and were maintenance free during the growing season except for regular inspection and topping up with water.

The results suggest that for optimal plant growth in terms of maximising size an irrigation tension of –50 hPa is best. Higher tensions of –100 and –200 hPa reduced plant fresh weight and also increased measured values of stomatal resistance which indicates that these plants were growing under greater moisture stress.

Raising the irrigation tension reduced the number of waterings given over the season and also reduced the overall volume of water consumed. Where water is expensive this could be of interest. In our experiments, any drainage water was collected and re-cycled. In conditions where drainage water is going to waste the water saving from reducing the number of irrigations would be much greater as the surface area of the pots is only about one third of the ground area at the spacing used. Therefore two thirds of the irrigation water is wasted.

The higher tensions reduced plant weight but plant appearance was not adversely affected as evidenced by the marketability results. In ornamental plant production maximising plant size is not necessarily the primary goal. This suggests that drier irrigation regimes could be used as a growth control agent with the beneficial side effect of a saving in water usage. The use of tensiometers would facilitate this approach. Again, this will be more attractive where water is expensive.

Ebb and flood irrigation used considerably less water than did the overhead spray lines. This may be exaggerated in our experiments because of the relatively small plot size and consequent loss of water from the system due to drift of spray in windy conditions. However evaporation of water from an overhead spray will always be much greater than that from the surface of the flooding water. The combination of re-cycling of drainage water with an ebb and flood irrigation system would be the most economical in terms of water usage.

Using a direct measurement such as a tensiometer for irrigation control means that a single pot must represent a population of containers. It is important therefore that the area under control is uniform and that the pot chosen for locating the tensiometer is representative. In practice, this will mean that a nursery using this approach will have to divide the growing area in to sections where plants of the same species and size i.e. the same water requirements, will be placed. The sections can then be controlled independently of each other. This requirement is no more than is need where the watering system is manually controlled. Care must also be taken to ensure that a representative pot is chosen. Spatial variations in the rate of watering from overhead systems can be a problem in this regard.

On a nursery with a number of tensiometers a central control system would be advantageous’ However the use of a digital tensiometer as an irrigation controller could easily be evaluated by using a simple circuit to switch a relay which could in turn start a pump or energise a solenoid valve.

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