Project title: Container HNS Irrigation: Use of capillary matting under protection

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HNS 107

Container HNS Irrigation: Use of capillary matting under protection.

Headline

- Capillary matting beds are a cost-effective method of irrigating container nursery stock under protection. They consume less than ⅓ the water of overhead sprinklers, and are about ⅓ the capital cost of Efford Drained Sand Beds.

Background and expected deliverables

The proportion of nursery stock grown under protection for some period during production continues to increase. While overhead sprinklers is the predominant irrigation method used outdoors, use of capillary sub-irrigation under protection can significantly improve water use efficiency, and has the potential to improve uniformity of water distribution compared to typical overhead systems. Sub-irrigation is also particularly appropriate for use under intensive protected cropping to minimise wetting of foliage to reduce disease, avoid accumulation of unsightly hard water deposits, and maintain plant quality.

Efford drained sand beds have been well proven over many years, but can be expensive to install. Capillary matting used as a primary irrigation method (and not simply as a secondary redistribution of overhead irrigation), may offer a cost effective alternative to sand beds for nursery stock production under protection.

There is a range of capillary matting materials on the market, but little independent research into their characteristics and performance had been undertaken. Also of interest was the development of the ‘capillary flow bed’, a gently inclined sub-irrigated bed, first described at the Geisenheim Institute, Germany.

The expected project deliverables were to:

- Compare key characteristics of capillary matting materials using standard tests.
- Develop the ‘capillary flow bed’ to assess its potential for irrigation of container nursery stock with promising capillary matting materials.
- Construct a semi-commercial scale capillary flow bed under protection, and compare this system to overhead sprinkler and Efford sand bed irrigation for water use efficiency, irrigation uniformity and growth and quality of a nursery stock crop.
- Test the potential of equipment available for automating control of a capillary matting system.

Summary of the project and main conclusions

Characteristics and requirements of capillary matting materials

The purpose of capillary matting is to link and distribute water from the delivery system to the bed (typically trickle hoses such as ‘T-tape’) to the root zone for each plant via holes in the base of the container.

A capillary matting needs to have:

1. Sufficient capillary action to redistribute water horizontally from emitter points to containers some distance from trickle lines such that adequate irrigation uniformity is achieved.

2. Enough capillary lift ability to cope with minor imperfections in the bed base, and avoid 'waterlogged hollows' or 'dry bumps'. Also, to hold water in the matting against a slight incline, so that perfectly horizontal sites are not essential, or when used with capillary flow beds.

3. Adequate water holding capacity (WHC). This is essential to enable good capillary contact between the growing medium in the pot and the matting to be maintained by reducing the hydraulic potential gradient across the matting / media interface. Mattings with too low WHC will dry too rapidly and cause capillary contact to be broken. The matting, however, does not function as large water reservoir, as the WHC may be small compared to daily evapotranspiration on a summers day.

4. A durable surface that will cope with traffic and handling of nursery stock containers on production beds at ground level. Some materials have an integral geotextile layer that can also withstand brushing to remove debris between crops. Otherwise it is usual to cover matting with a layer of permeable woven polypropylene groundcover (e.g. Mypex 'Red Stripe'), or Texel Tex-R non-woven fabric as done with sand beds.

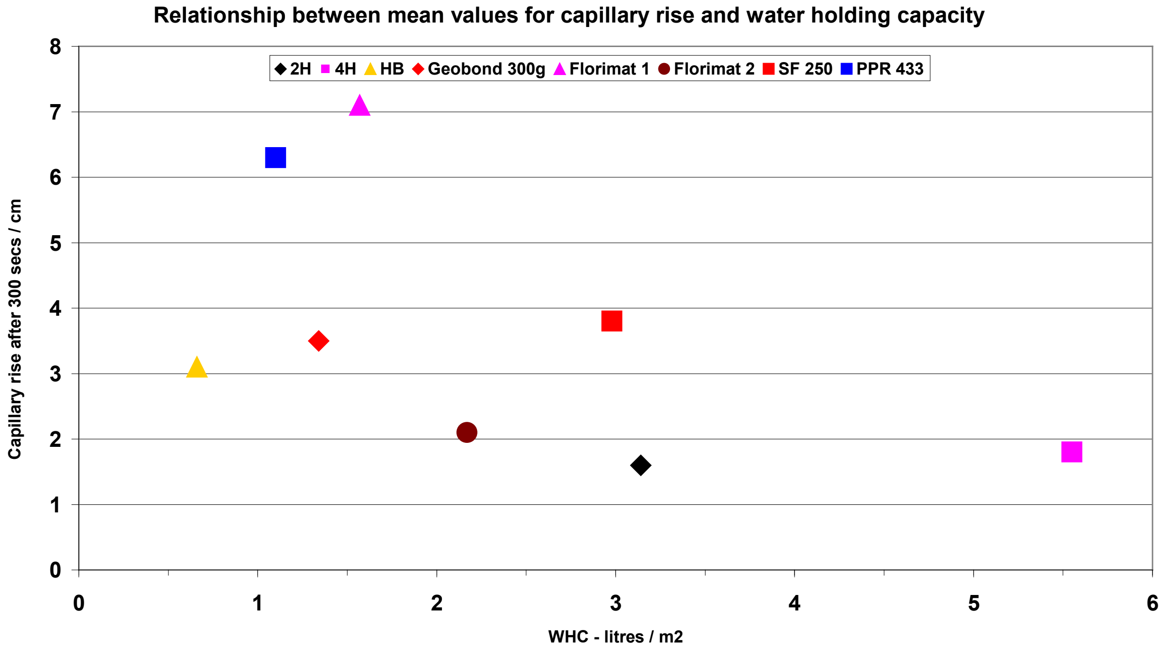
5. Durability to cleaning and disinfection agents, e.g. Jet 5 (a.i. 5% peroxyacetic acid), and to acidified water. Build up of bicarbonate and salt deposits from hard water and fertiliser will significantly affect the matting's capability to absorb and move water. Jet 5 will remove these deposits in addition to disease control, but acidification of hard water supplies will minimise accumulation in the first place.

Capillary mattings examined during the project

Supplier	Type	Composition
Anglo Felt Industries via Geerings	Indoor Matting (2H)	Wool based. Black
	Outdoor Matting (4H)	Wool based. Black
	Prototype 9206 (HB)	Cotton based. Black
	Algon 2H and 4H	As above but with an easily cleaned non-woven bonded top layer
* Tildenet	Geobond 300 g	Synthetic / wool blend. White with bonded black geotextile top layer
* Bato Trading	'All-In' matting	Synthetic. Black. Incorporates geotextile top layer and impermeable base membrane
Flowering Plants	Florimat 1 – 'High Rise'	Synthetic. White
	Florimat 2 – 'Middle weight'	Synthetic. Black
* Fibertex	SF-250 PPR 433	Synthetic. (Polypropylene / Polyester / Viscose blends). Both types grey
Fyba Pot Co.	Fybamat	Synthetic (polyester). White

* N.B. These products are no longer commercially available in the UK

- Methods for determining WHC and vertical capillary lift of several matting materials were carried out in Year 1 using DIN Standards DIN 53923 and 53924 (1968) sometimes referred to by matting suppliers. These tests were originally applied for fabrics used for domestic tea towels or medicinal use, and not for horticultural capillary mattings! It was difficult to observe vertical capillary rise accurately, particularly with dark mattings, and there were also some significant discrepancies between data quoted by suppliers and our results. While, with modifications, these tests may have some value for comparing some properties of materials, it proved difficult to establish a quantitative relationship between these data and subsequent practical performance of the matting with a crop. However, high capillary lift ability of mattings often related to low WHC and vice versa:



- A test was developed to compare the ability of mattings to deliver water to pots of growing media and maintain an equilibrium moisture content. Pots were arranged in rows on matting covered test benches set at a 10% incline. Water was freely available in a channel at the base of the slope, and pots, which were all initially wetted to capacity, were weighed at daily intervals until steady weight had been reached. The method showed some promise, with pots at the top of the slope eventually becoming very dry and lightweight, while those nearer the base remained constantly moist. The clear point up the slope where capillary contact had been broken depended on factors including the type of matting. However this test proved tedious and equilibrium was slow to develop under autumn / winter conditions.

- In early tests, addition of a layer of Mypex or Tex-R to mattings such as Florimat 2, that did not incorporate a suitable hard-wearing top layer, could markedly affect the ability to maintain capillary contact between containers and the matting as it dried down. This was mainly a problem, however, with lighter 9 cm pots, and not the 2 and 3 litre container grown crops used later in the project.

- Some mattings were easier to initially wet up when new or fully dried out. Geobond 300g, for example, was more hydrophobic or water repellent than Algon or Florimat types. Addition of a wetting agent when soaking up mattings for the first time may be beneficial with some mats.

- A range of mattings can give good results when managed appropriately. It was not therefore possible to define optimum specifications for mattings, but only provide broad guidelines. From observations in this project, materials suitable for a primary irrigation system for nursery stock beds are likely to be at least 2 – 3 mm thick, and have WHC of over 1 litre / m^2 but less than 5 litres / m^2. A vertical -capillary lift ability of 40 mm or more is also desirable. Mattings based on both natural fibres (e.g. wool / cotton) and synthetic fibres can give good results.

Capillary flow bed – construction and management

- If laid at ground level, the base needs to be reasonably smooth and firmed, and ideally levelled flush with timber edging. Soil should be raked and the surface finished with about 20 mm depth of firmed sand. Tests have shown performance of mattings should not be adversely affected by 'bumps and hollows' of 1 cm in the bed surface, (larger tolerances were not tested).

- A layer of polythene is required to line the bed underneath the capillary matting. A few capillary matting products incorporate a polythene or similar basal layer.

- A slope across the bed to aid water distribution and drainage of surplus is integral to the design of the capillary flow bed. Although not tested in this project, nursery stock over-wintered on outside beds are particularly likely to need a well drained inclined capillary bed to avoid waterlogging from rainfall. A 2 – 3% incline gave better distribution than a 1% gradient of water from trickle lines offset up the slope on small-scale experimental beds. However, on larger scale beds with a nursery stock crop there was evidence for slightly wetter containers at the bottom of a 2% incline, although this did not appear to affect plant root or shoot growth. Commercial literature recommends that the fall over a continuous width of matting does not exceed about ⅔ the vertical capillary lift ability of the material. For matting with a 75 mm lift, this would allow up to a 50 mm fall over the slope. For a 2.5 m wide bed, this is equivalent to a 2% gradient. For wider beds, either a gentler incline is required, or areas of matting are separated with a gap to break the capillary link, and are treated as subsidiary beds. It was not possible to confirm these recommendations independently, partly because of the practical problems in establishing capillary rise data and discrepancies between our data and that quoted by suppliers.

- Correct spacing of T-tape irrigation lines is essential to achieve uniform wetting. Gravity helps distribute water across a sloped bed, but nevertheless T-tape lines should be spaced no further apart than 75 – 100 cm. With a sloped bed, lines are 'offset' up the slope with the first line positioned near the top edge, and the lowest line three or four rows inside the lower edge.

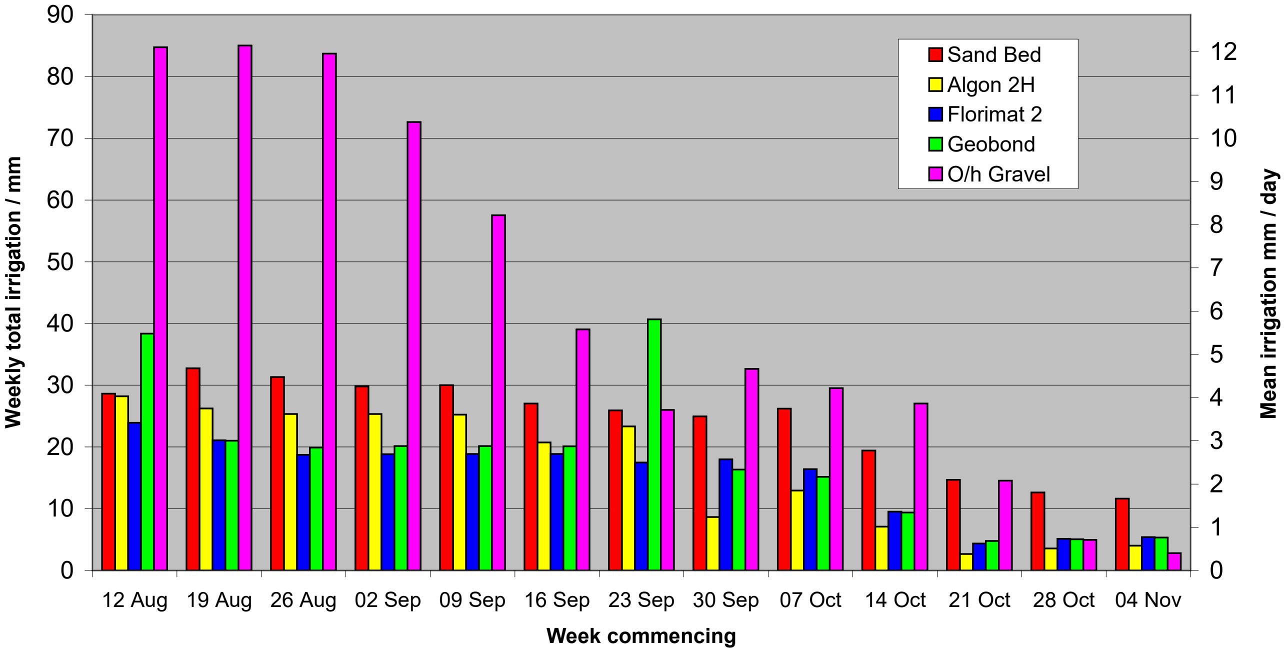
- Acidification of the hard water supply was necessary to avoid rapid build up of bicarbonate deposits in the summer, and the development of 'hydrophobic' or water repellent patches on the matting.

- Irrigation control was equally successful using time clocks and Flowering Plant's 'Water Bug' controller during experiments in late summer / autumn, and spring / early summer. In practice, when irrigating *Pittosporum, Ceanothus* and *Ceratostigma*, time clocks did not require as frequent adjustment to cope with changes in evapotranspiration demand as was expected. The Water Bug is designed to automatically switch irrigation on and off according to demand. It worked satisfactorily, but still needed a similar number of adjustments as the season progressed as did time clocks.

- Mattings should be fully wetted up at each irrigation cycle to ensure rapid uptake into containers, and minimise the development of dry patches. However, run-off from sloped beds usually indicates it is being run too wet. Currently the optimum frequency and duration of irrigation has to be determined by trial and error by observing the crop. As well as being affected by the plant and container size, and weather, this will be affected by the type of matting. A thicker matting with a higher water holding capacity will normally require slightly less frequent but heavier irrigations, provided it can maintain capillary contact at the dry part of the cycle. In general, though, it is not possible to implement an irrigation schedule with large wet / dry fluctuations automatically using capillary irrigation.

Water consumption

- The capillary matting flow bed was monitored alongside an Efford sand bed and a well designed overhead sprinkler system under glass using similar layouts of a range of shrubs in 3 litre pots. Over the experiment (12 August to 6 November), water consumption of the mattings averaged 2.5 mm / day compared to 3.6 mm / day for the sand and 6.4 mm / day for the overhead systems. Water savings for the capillary systems were greatest when demand was highest. Taking into account data from elsewhere, capillary matting and sand bed systems consume 25 – 35% that of overhead sprinklers (less still when compared to poorly managed overhead systems).



- Differences in water consumption between matting types were relatively small. N-S position in the glasshouse affected water use to a similar degree. Water use from 6 January to 30 May in a second experiment using Florimat 2 alone averaged 1.3 mm / day.

Uniformity of water distribution and plant growth

- Uniformity of water distribution was estimated by weighing samples of pots across beds for each system during the autumn 2002 experiment. Uniformity of watering was as good from the capillary matting flow beds as with the Efford sand bed.

Surprisingly, as good or better uniformity of watering was possible from overhead irrigation, but only because pots tended to be watered to excess with surplus running to waste. During hot periods when some pots began to dry out, uniformity was poorer with overhead sprinklers.

- There was a slight tendency overall for containers to be wetter on the lower side of the inclined beds, though Florimat 2 maintained slightly more uniform water status than the other two mattings. Pots also remained wetter overall on Algon 2H. However none of the three mattings tested required more or less ‘spot waterings’ by hand. Differences in water consumption due to species (size and vigour of plant) were much more important. While the three *Pittosporum* and two *Ceanothus* subjects had similar requirements, *Ceratostigma griffithii* grown on the same beds needed additional spot waterings.
- Plant growth was unaffected by any slight differences in moisture status across the capillary beds, and was equally good on all three matting types and the sand bed. Plants were distinctly smaller, however, from the overhead irrigation system. This was particularly marked for *Ceanothus* ‘Concha’, *Pittosporum* ‘Wendle Charron’ and *P.* ‘Abbotsbury Gold’. Hard water deposits were also most severe on the foliage of these subjects and while this probably was mainly responsible for the reduced growth, less nitrogen would have also been supplied to these plants compared to the capillary systems acidified with nitric acid.

Growth of *Ceanothus* ‘Concha’ on capillary matting, overhead and sand beds (left to right)

Hard water deposits on overhead irrigated *Pittosporum* ‘Tom Thumb’ (right) compared to capillary matting watered plant (left).

Economics

- The cost of the matting is the largest component of the material costs for installing capillary flow beds. Matting prices vary, but about £1.75 / m^2 is typical for matting without an incorporated geotextile layer. Total material costs for a capillary flow bed using timber sides and a levelled base, and T-tape irrigation lines could be about

£3.40 / m^2. Efford Drained Sand Beds are about £10 / m^2. Additional costs would include irrigation connections to the supply, valves, drainage from beds, irrigation control kit and acid dosing equipment if required.

- Acidification of hard water supplies is a worthwhile extra cost to maintain performance and reliability of matting irrigation, particularly for protected cropping systems.

Financial benefits

Efficient irrigation of nursery stock will be an essential requirement for all nurseries in the future, following the implementation of new water legislation. Given that minimum water savings of 65% are likely compared to overhead systems, it is likely that capillary irrigation will be particularly attractive to nurseries wishing to expand or upgrade their production areas. The capital cost of installing capillary matting beds is also about 1/3 that of Efford Drained Sand Beds. Preparation of the bed surface requires some care if good results are to be achieved, but DIY construction is within the capability of most nurseries and is less demanding than for Efford Sand Beds. Use of capillary matting beds outside has not been examined in this project, but under protection, plant growth has been as good as on sand beds, and risks of waterlogging of plants over winter is minimised.

Successful implementation of capillary irrigation is less about choosing a matting with the right specification or most attractive price and more about correct installation and irrigation management to suit the crop

For production of nursery stock under protection, capillary matting beds offer cost effective sub-irrigation with other advantages over sprinkler systems such as maintaining dry foliage and pathways, and confining water application to the cropped area.

Action points for growers

- Consider installing capillary matting sub-irrigation under protection as a less capital intensive option than sand beds, and a more water efficient alternative to overhead sprinklers. It is best suited to subjects that prefer an even irrigation regime and that do not require too much drying back between applications. Also for species where water on the foliage or flowers can be damaging through scorch, deposits or disease.

- Ensure sites are graded and levelled before laying matting. Where inclined capillary flow beds are to be installed, construct with the slope across, not down, the bed.

- Acidify hard water supplies used for capillary matting.

- Take care to establish good capillary contact at the start of the crop with thorough watering and settling of the growing medium. Learn what frequency and duration of watering is needed to maintain capillary contact, for the particular matting and crop.

- As with other irrigation systems, it is important to avoid mixing subjects with different water requirements on beds receiving the same irrigation regime.

Acknowledgements

Thanks is extended to Flowering Plants Ltd for supply of matting materials and loan of Water Bug controller devices. Also to Anglo Felt Industries Ltd for the supply of matting samples.

Finally we are grateful to Lees & Co. Wholesale Nurserymen, Portmore, Lymington, for the loan of the nursery stock plants for the final year of the project.

SCIENCE SECTION

INTRODUCTION

Year 1 of this project examined the basic physical characteristics of several capillary matting materials, and important properties required for a primary irrigation system suitable for container nursery stock.

A number of experiments in Year 2 used an array of small experimental beds under glass to test parameters such as the gradient, irrigation layout and management etc. required for the successful operation of a 'capillary flow bed'.

Having tested the capillary flow bed using small prototype beds and establishing the working tolerances of a number of capillary mattings, in this final Year 3 of the project, a larger commercial scale 'flow bed' was constructed in a glasshouse alongside an Efford Sand Bed, and an overhead sprinkler system. Comparisons were made of water consumption, uniformity of irrigation and crop growth.

Details of the project layout and the results are complemented by photographs presented in Appendix 2.

Objectives – Year 3

To construct a larger scale capillary flow bed under protection comparing this system to overhead and sand bed irrigation.

The main objectives of comparing the three irrigation systems were to:

1. Assess and compare water consumption for the crop
2. Measure and compare uniformity of water distribution (uptake by the containers)
3. Compare crop growth and uniformity.

The primary objective of a second experiment in this final year was to further evaluate the Water Bug device as an alternative to time clocks to manage irrigation scheduling with capillary matting. Secondly, it enabled further information on water consumption to be gathered.

MATERIALS AND METHODS

Treatments - Experiment 1 August - November 2002

Irrigation systems

1 Efford drained sand bed
2 Overhead irrigation on gravel
3 Capillary flow bed comparing 3 matting types -
    Algon 2H (Anglo Felt Industries Ltd)
    Florimat 2 (Flowering Plants Ltd)
    Geobond 300g (Tildenet Ltd)

Algon mattings have a bonded surface layer on top of the main felt surface, allowing for easy cleaning of the surface of debris by brushing, while still maintaining close capillarity with the body of the mat. Geobond has a woven polypropylene hardwearing geotextile surface layer through which some of the underneath matting fibres have been pulled to aid capillary continuity. Florimat 2 was used with a layer of Mypex 'Red Stripe'; one of the proprietary geotextiles recommended by Flowering Plants Ltd.

Plant species

Ceanothus 'Concha'
C. 'Pappilosus'

Ceratostigma griffithii

Pittosporum tenuifolium 'Tom Thumb'
P. 'Wendle Charron'
P. 'Abbotsbury Gold'

Layout

See Appendix 1, Fig 1. The main plots comprising a block of each species was replicated 3 times down the Efford sand bed and Overhead irrigation system beds. The capillary flow bed was split into a single plot of each matting type.

Treatments - Experiment 2 January - May 2003

This experiment used just the capillary flow bed with a single matting type, Florimat 2, on all three main plots.

Irrigation system control

Plot 1	(North end)	Water Bug control
Plot 2	(Middle)	Time clock control
Plot 3	(South end)	Water Bug control

Plant species

Ceratostigma was excluded from this experiment. Additional plants of the remaining species, of similar size and quality, were taken from the Experiment 1 sand bed plots to make up plant numbers for Experiment 2.

See Appendix 1, Fig 2 for details of Experiment 2 layout.

Details of irrigation systems and general methods

Sand Bed

The sand bed was constructed as two half beds 11.25 m long x 1.6 m wide. There were 270 plants consisting of a mixture of species per half bed so a total of 540 plants over all the sand bed. They were spaced 25 cm apart. The bed was covered with 'Red Stripe' Mypex to protect the sand and reduce rooting through. The irrigation control was by time clock with water being applied via two trickle lines on each half bed therefore a total of four trickle lines over the whole sand bed. Acidified water at pH 6.2 – 6.5 was used on both this and the capillary matting system to avoid problems with hard water.

Capillary Flow Bed

The capillary matting bed was 15.9 m long by 2.5 m wide with a 2% cross-width gradient. There were a total of 540 plants on the whole capillary matting bed with 10 rows spaced 250 mm apart. The bed was split into three main plots. Each plot had a different capillary matting type containing 180 plants each over an area of 5 m x 2.5 m - Algon 2H, Florimat 2 + Mypex and Geobond 300g. Each plot had individual time clock controlled irrigation via three trickle lines for the initial experiments, but the facility allowed for automatic control by a 'Water Bug' for later experiments. The first and second irrigation lines were spaced three rows (0.75 m) apart, the third line a further four rows (1.0 m) down the bed leaving a final three rows before the lower edge. The polythene base sheet overhung some guttering in a channel along the lower side of the bed into which any surplus water could run. This was collected separately for each of the three plots. The time clock settings were adjusted according to the individual requirements of the different mattings. Irrigation water was acidified as above.

Overhead Sprinklers on a Gravel Bed

The overhead sprinklers were placed 2 m apart down line x 3.5 m between laterals over two gravel half beds of 11.25 m x 1.6 m. The overhead sprinkler irrigation was controlled by a single time clock and adjusted according to the requirements of the plants. Acidification of the irrigation water was not practical with the overhead system, so plain mains water was used. There were 270 plants consisting of a mixture of species per half bed giving a total of 540 plants over all the gravel bed. They were spaced 25 cm apart.

Assessments

Records included the following:

1. Applied water from all three irrigation systems.
2. Run-off water from the capillary matting bed.
3. Pots from a number of different areas of the beds weighed to assess water distribution.
4. Plant growth (e.g. height, bushiness, new growth).

In collaboration with a local nursery, a commercial crop of liner plants was loaned for the duration of the final year of the project. Plant growth assessments were therefore non-destructive.

Water consumption was measured with a water meter for each of the overhead on gravel and Efford sand bed systems, and a separate water meter for each of the three capillary matting main plots. Data for water consumption was converted to mm use by dividing by the consumption in litres by the irrigated area in m^2:

Sand bed - 11.25 m x 3.95 m (including centre path within bed) = 44.4 m^2

Capillary flow bed - 5.0 m x 2.5 m = 12.5 m^2 for each of the 3 main plots

Overhead sprinklers - two laterals 3.5 m apart, each of seven sprinklers spaced at 2 m = 98 m^2
(Note that the actual cropped area was 11.25 x 3.5 = 39.4 m^2, but the irrigated area calculated as if it were within a larger commercial block with irrigation lines at this spacing.)

Weighing sample pots

Appendix 1, Fig. 1 shows the plants selected for weighing in each system to estimate uniformity and degree of wetting. A representative set of pots covering the bed areas was used first (shown in yellow). This included the top and bottom rows of the sloped capillary beds as well as two rows down the middle. For the sand and gravel beds, however, edge pots were avoided. Initially pots were weighed several times a week. However, it was found that this regular disturbance could break capillary contact of pots with the capillary matting or the sand, particularly if pots were 'becoming dry'. Once capillary contact had been broken, pots continued to dry out and become lighter, and unrepresentative of those surrounding them. To get around this problem, additional sets of pots were selected and weighing each set of pots was only undertaken once a week on Mondays (yellow), Wednesdays (red) and Fridays (green). Where possible, weighing of pots was also timed to avoid just before or during irrigation periods when pots might be at their lightest. Finally, any abnormally dry pots encountered during sampling were weighed and recorded, then wetted up by hand to re-establish capillary contact. Once the plants had settled in and the appropriate time clock settings established for each bed, few recorded pots needed hand watering.

To speed up the weighing procedure, loops of wire were fixed to each recorded pot. Pots were then easily weighed using an electronic suspension balance (Electro-Sampson model - Salter Scales), by hooking and lifting them without having to remove them from the bed.

Plant handling / potting

9 cm liners of these species were pruned and potted into 3.0 litre containers in late April 2002. A pre-mixed bulk supply of an open textured HNS container mix of the following specification was used:

Peat: 30%v/v medium grade + 55%v/v medium / coarse grade +
Bark: 15%v/v 5-12 mm container grade.
CRF - 1.0 kg/m^3 Sincrostart 12+14+24+3MgO+traces plus
4.5 kg/m^3 Sincrocell 12 month 14+8+13+2MgO+traces
SuSCon Green 0.75 kg/m^3
Lime to pH 5.8
Wetting agent (unspecified)

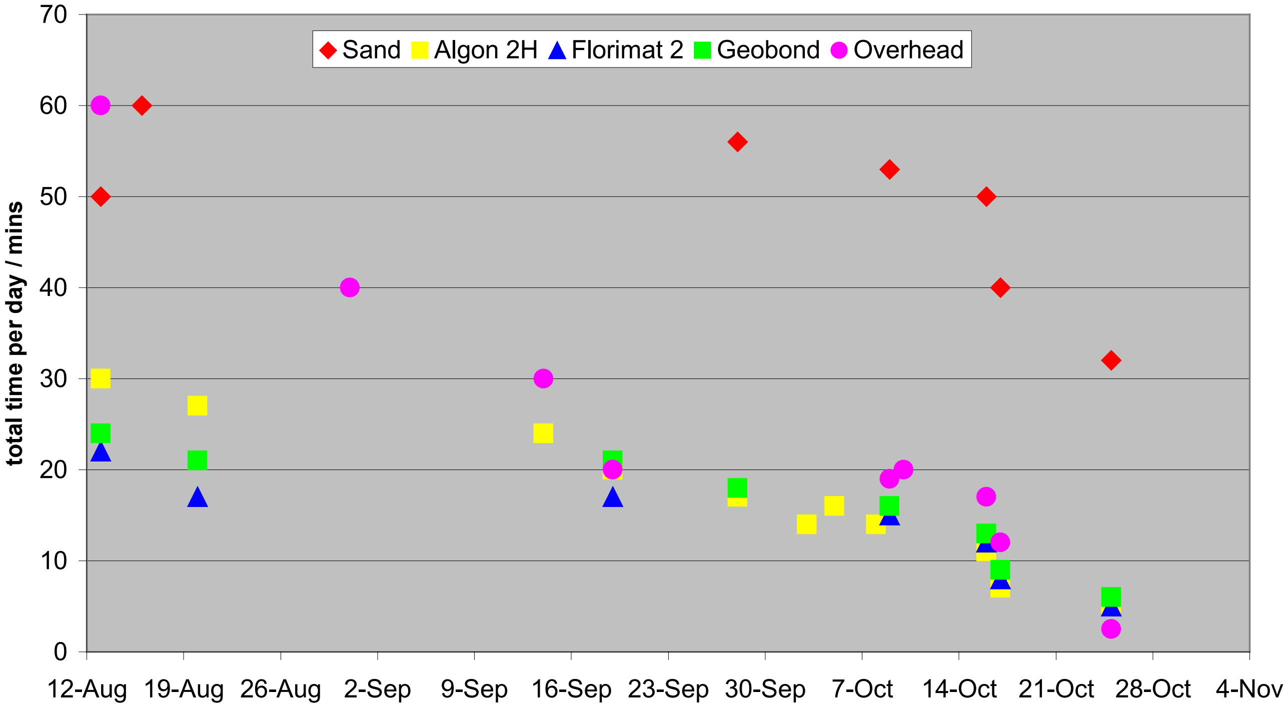
Containers were moved onto the comparative production bed systems in June once construction and testing was complete. *Ceratostigma* was more vigorous and spreading than the other species, and required extra watering by hand. Pruning of all species was carried out again on 31 July to even up plant size, maintain shape and to minimise water use differences between species as far as possible before the commencement of the trial recording.

RESULTS AND DISCUSSION

Experiment 1: August - November 2002

Water Use between Irrigation Systems

Figure 1 Irrigation time clock settings for each system during Experiment 1



The time clocks for each treatment were adjusted periodically based on observation of the plants, wetness of growing media and, for the capillary matting treatments, evidence of runoff. Irrigations were typically applied in three doses per day for the sand and capillary matting systems and twice a day for the overhead sprinklers. The total daily irrigation times are shown in Fig 1. Note, however, that the application rate of water per unit area was much greater for the overhead sprinklers than for the T-Tape fed capillary systems. Also that four lines of T-Tape were used on the 3.95 m wide sand bed including centre path (0.98 m / tape) compared to three lines on the 2.5 m wide capillary matting bed (0.83 m / tape). Thus direct comparisons of water use cannot be made between the three systems from Fig 1. Water use data is shown in Fig 2, and a summary of mean daily water use in Fig 4. External solar radiation data, which is the main environmental driver for water loss, is given in Fig 3.

Figure 2 Water use for Experiment 1 (mm irrigation applied per week)

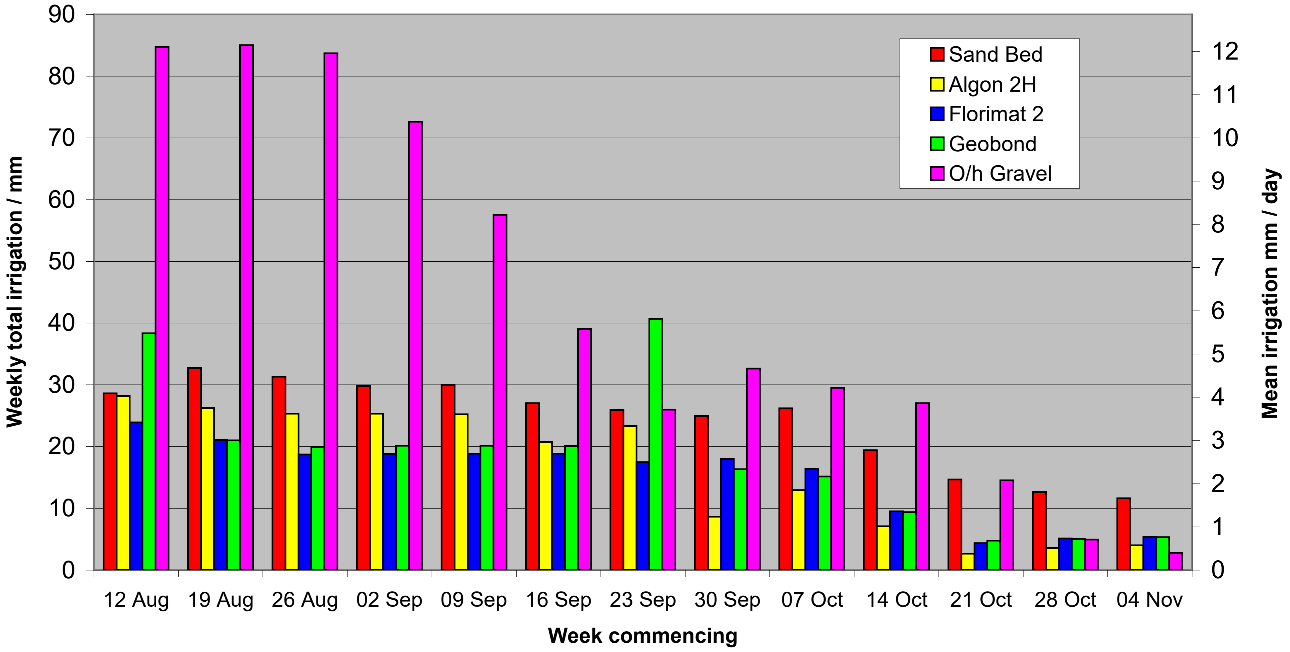


Figure 3 Outdoors solar radiation during Experiment 1 (weekly total MJ/m^2)

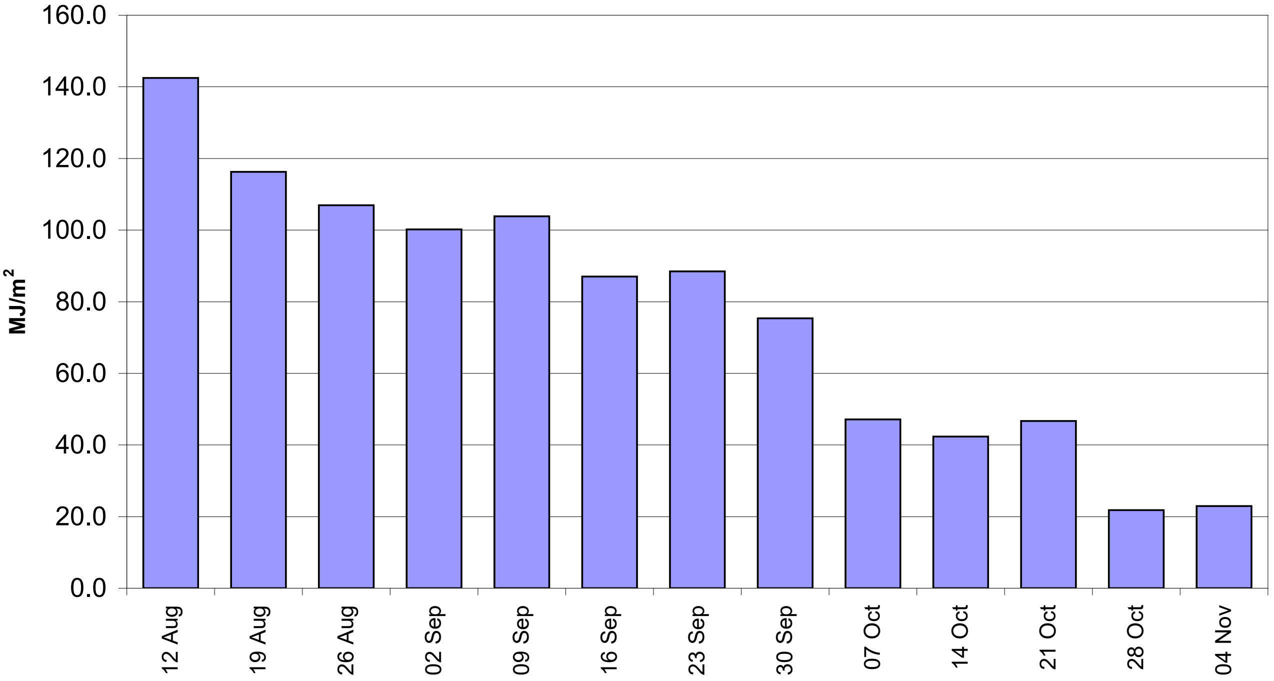
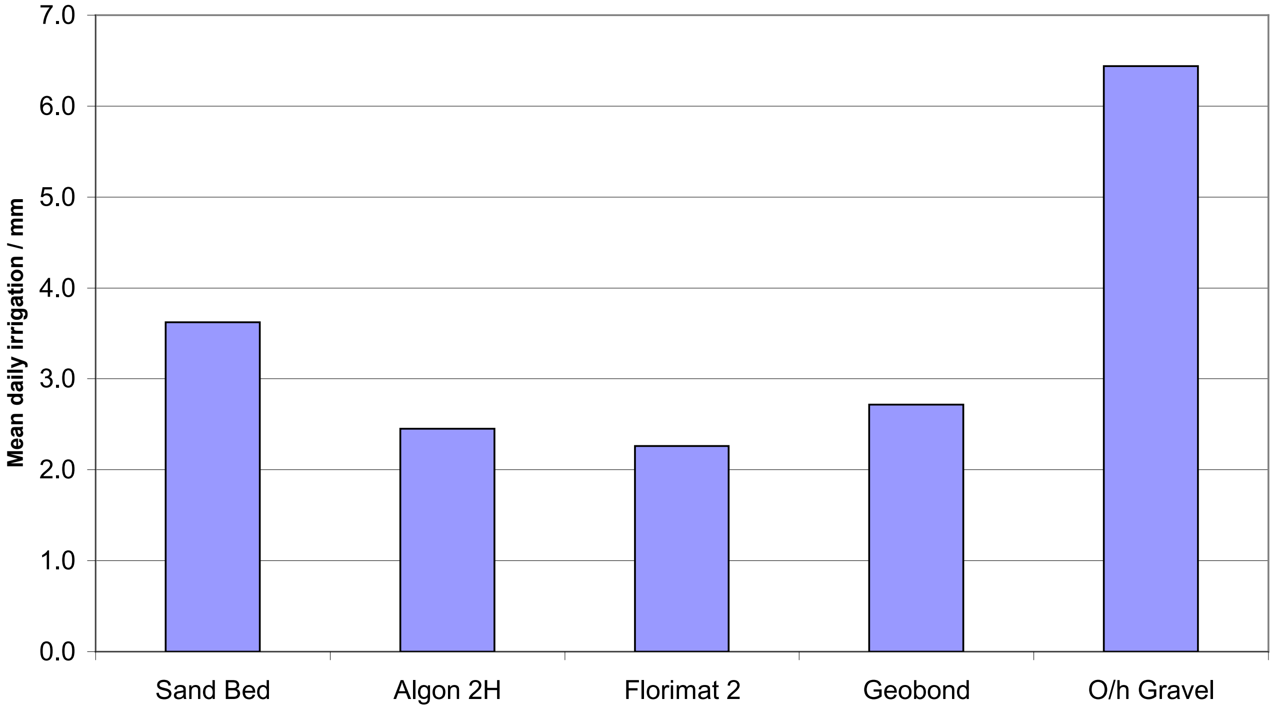


Figure 4 Mean daily irrigation mm / day for Experiment 1 period 12 Aug - 6 Nov



Not surprisingly, overhead sprinkler irrigation used much more water than either the sand or the capillary matting beds. The pattern for water use over the late summer - autumn period broadly followed that for solar radiation for sprinkler irrigation. However, this pattern was not followed so closely for the sand and capillary matting beds, with a flatter water use profile until late Sept - mid October when it dropped off markedly. On average, the overhead system used two to three times the water of the subirrigation systems, but during times of high demand in the summer, the factor was up to four times as much. The calculation for the overhead sprinkler water use based on the nominal irrigated area covered by two lines is also likely to be a slight underestimate given that the cropped area will always be a bit less than the actual wetted area in a well designed system.

Interestingly, the sand bed consumed more water than the capillary matting beds in this experiment. This bed was covered with Mypex, and it was found that it was necessary to keep the sand quite wet in order to maintain good capillary contact with the potting media.

There was relatively little difference in water consumption between the three capillary matting beds, which averaged 2.3 - 2.7 mm / day over this period (Fig 4). Florimat 2 had the lowest mean water use, but it is not possible to make reliable judgements of small differences in water use between these mattings, as effects may have been confounded with positional differences of the unreplicated plots in the glasshouse. It is quite possible that the slightly higher water use for the Geobond plot may have been due to it receiving more exposure to sun at the south side of the house.

When the capillary matting beds were running satisfactorily, there was no surplus runoff from them, i.e. sufficient irrigation was applied via the T-tape to wet up the matting and growing media, but without any surplus running to waste. On a few occasions, such as when weather turned dull after an extended bright period, some run off was collected. This was usually an indication that the irrigation time clocks needed adjusting downwards. Some run-off might also occur after additional spot watering by hand lance.

Finally, it is important to recognise that two opposing factors were affecting water consumption. While total solar radiation was declining from August to November, the crop, which had been hard pruned at the start of the experiment, was growing and thus demanding relatively more water. This might partly explain why water consumption by the sub-irrigation treatments did not decline as rapidly as would be expected from the solar radiation data. Also, some irrigation was maintained daily on both sand and matting beds throughout the experiment to ensure capillary contact with the base was maintained. With the overhead sprinkler treatment, plant growth was not as vigorous as with the sub-irrigation beds (see on), and therefore would not have demanded as much water late in the experiment. Also, it was noticed that some plants (mainly *Ceratostigma*) had rooted through into the gravel on Mypex base at the end of the experiment, allowing access to additional water to that which reached the pot from overhead.

Water Use between Species

The objective of the experiment was to compare water use between irrigation systems, and not between species. Species had been selected for this stage of the project in the belief that they would have broadly similar water requirements, and could all be grown under the same regime, as is necessary on a typical commercial HNS bed. However, it became clear during the plant establishment phase after potting on liners in late April that *Ceratostigma* grew more rapidly and required more frequent watering than the other species. Pruning plants back to a similar size prior to commencing recording for Experiment 1 had the desired effect of unifying water demand between species, but by the end of the experiment, *Ceratogstigma* had again outgrown the other subjects, and some additional spot watering was required occasionally on this subject. This additional watering with a hand lance was not metered and therefore not included in the water use data presented above.

Uniformity of water status in the crop

Water status within the crop was estimated on the basis of pot weights using the data obtained as described above. Plants were only weighed once on the days they were recorded, and not before and after an irrigation cycle as used in the Water LINK project HNS 97. The objective was not to assess water application distribution by the irrigation delivery system *per se*, but to get an indication of uniformity of water status in the pots over the different cropping beds, as a series of regular ‘snapshots’ throughout the experiment. Clearly differences in plant size and volume of growing media between containers will affect the gross weight measured, as well as water content of the media. From experience, however, when using a reasonably large sample, this crude method gives an adequate indication of pot water status over an area, as water in the growing medium is a large proportion of the gross weight.

Uniformity of water status across slope of capillary matting beds

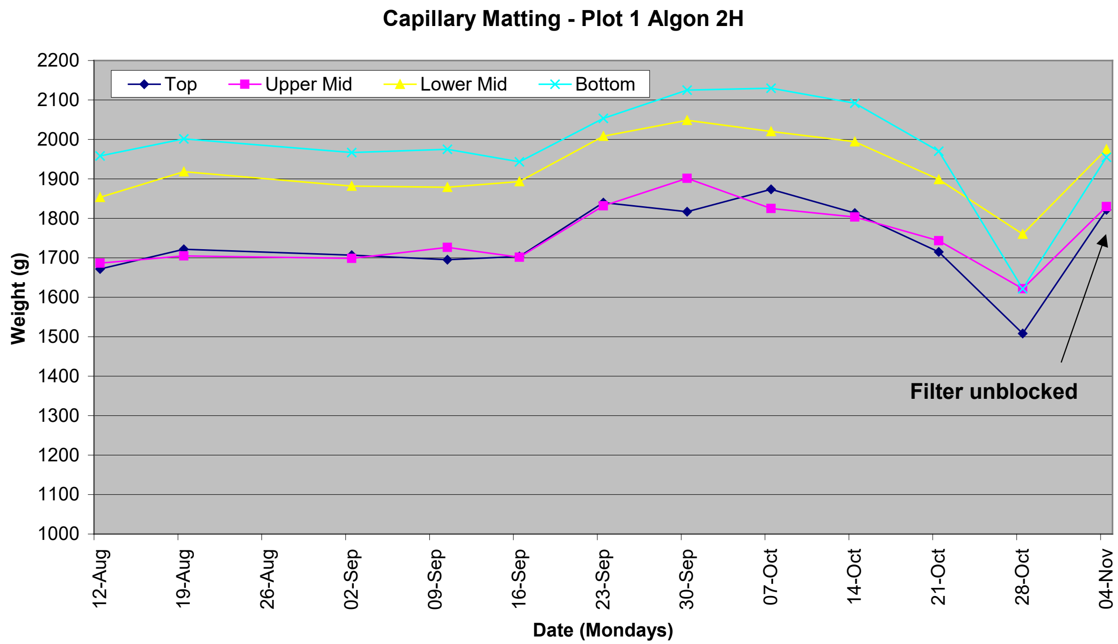
Of particular interest with the capillary matting systems, was the whether the configuration of the cross-sloped beds with three T-tape trickle lines off-set to one side up the slope, would aid good uniformity of pot watering.

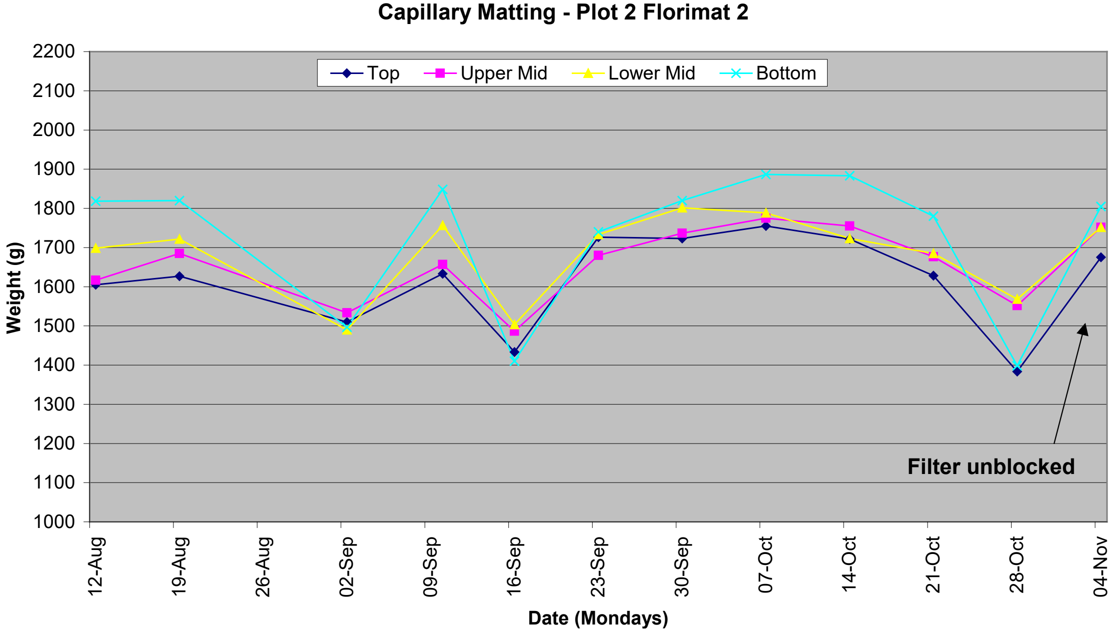
Figures 5 - 7 below show the results for the Monday, Wednesday and Friday sets of containers respectively. Note that the scale has been chosen to emphasise mean pot weights in the 1000 - 2200 g / pot range. The samples were categorised according to their position on the slope across the bed as Top, Bottom, Upper Mid and Lower Mid (see Appendix 1, Fig 1). Each data point is a mean weight of six containers. Because different containers were sampled on different days of the week, which were usually in adjacent rows, care must be taken when comparing results for the mattings between sampling sets. For example, pots from rows adjacent to the outside rows were necessarily used for 'Top' and 'Bottom' positions for the Wednesday and Friday samples. These three weekday sample sets, however, do give a degree of 'replication in time' for the experiment and a good indication of how even water status of the pots is down the slope.

The effect of an accumulation of algal debris in the system filters is illustrated in Figures 5 and 6. Over the second half of October, plants began to dry back and containers became generally lighter. This trend is clear across all the data sets in Figs 5 - 7. Part of this was because time clocks had been adjusted to reduce irrigation doses, the last adjustment being made on 25 October. However, on Friday 1 November, some plants had become excessively dry, and it became clear that dirty filters were restricting the T-Tape output. Once cleaned, the water flow increased without the need to adjust the time clocks, and was responsible for the increased container weights for the final two records on Monday 4 and Wednesday 6 November.

There was evidence of some gradient in water status in the containers across the bed, with a trend towards heavier pots at the bottom of the slope and lighter pots at the top and upper middle. However, this was not consistent. The pots at the top of the slope were heaviest with Algon 2H for the Wednesday and Friday set, but not Mondays. Pot weights for Florimat 2 were relatively uniform across the bed for the Monday sample set, but less so for the other two samples. However, while there may have been differences in mean container weights due to position on the bed of up to 400 g, once plants had become established on the capillary matting system throughout Experiment 1, there was no evidence of excessive dryness, waterlogging, or effect on plant growth, as a result of position on the bed. When constructing the bed, it was important to ensure the sand or soil base substrate remained flush with the wooden board edging to prevent an accumulation of any surplus water. Some additional sand to build up the lower edge of the bed was necessary after initial settlement during the set-up phase.

Figure 5 Capillary matting pot weights over bed - Mondays sample set





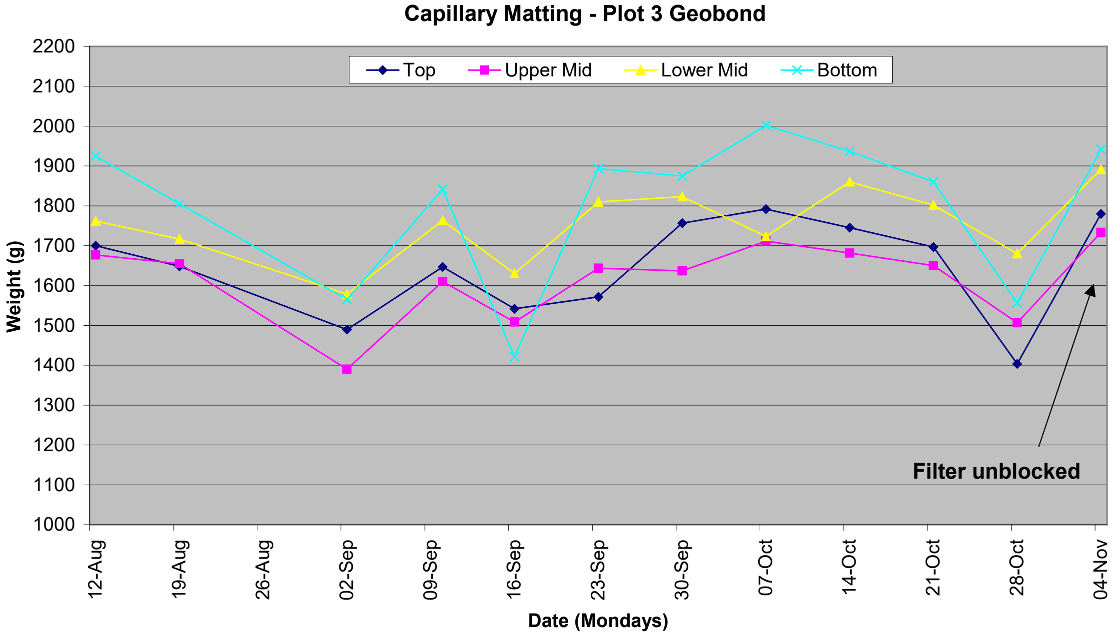
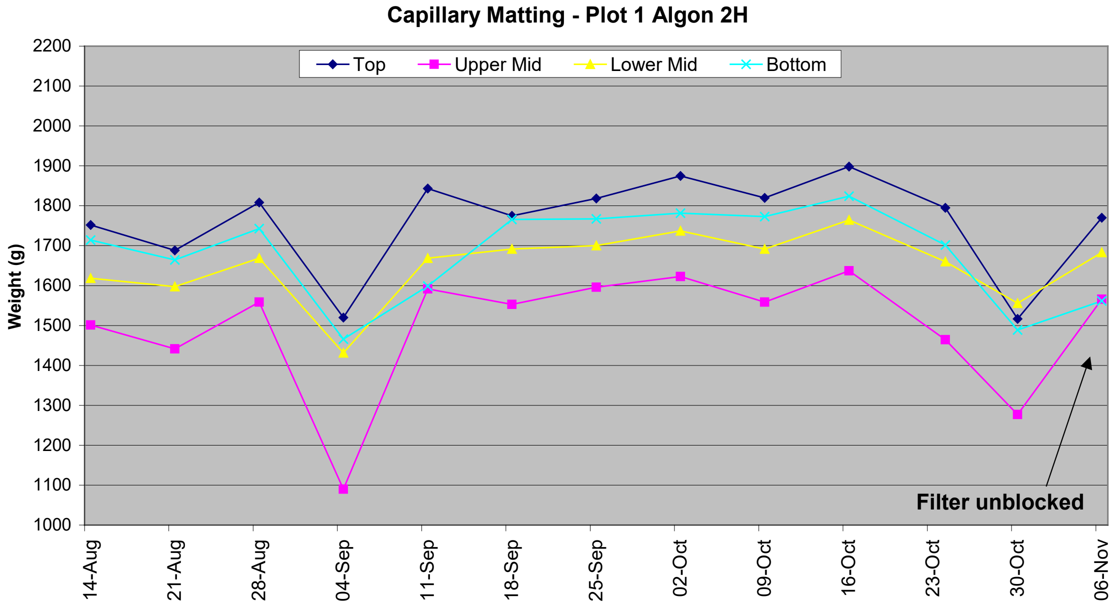
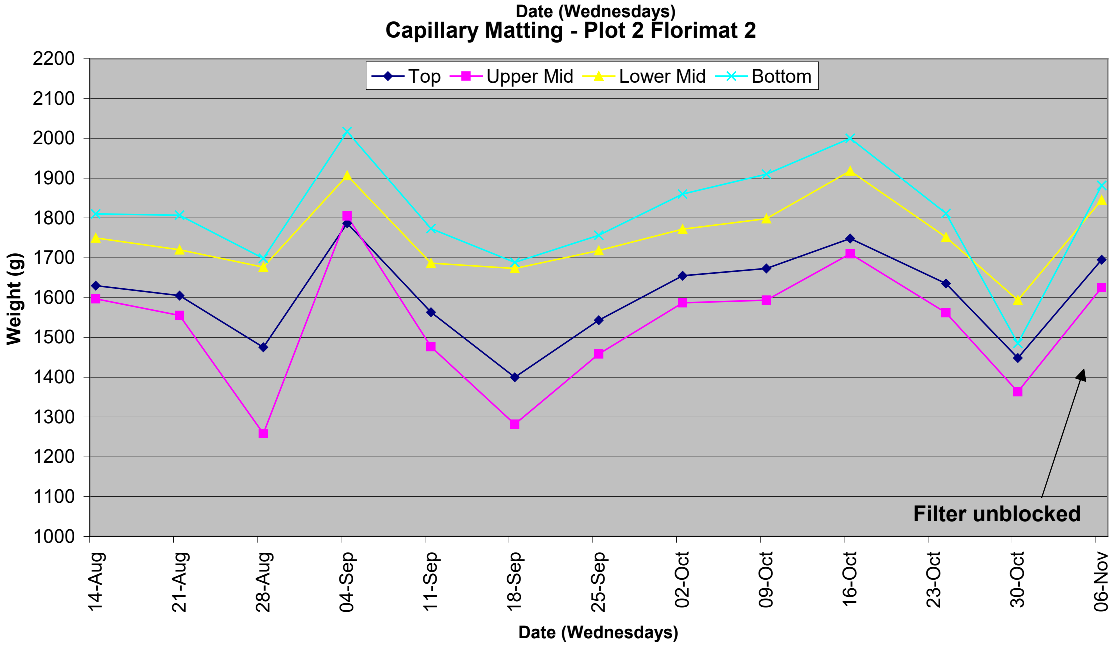


Figure 6 Capillary matting pot weights over bed - Wednesdays sample set


Capillary Matting - Plot 1 Algon 2H


Capillary Matting - Plot 2 Florimat 2

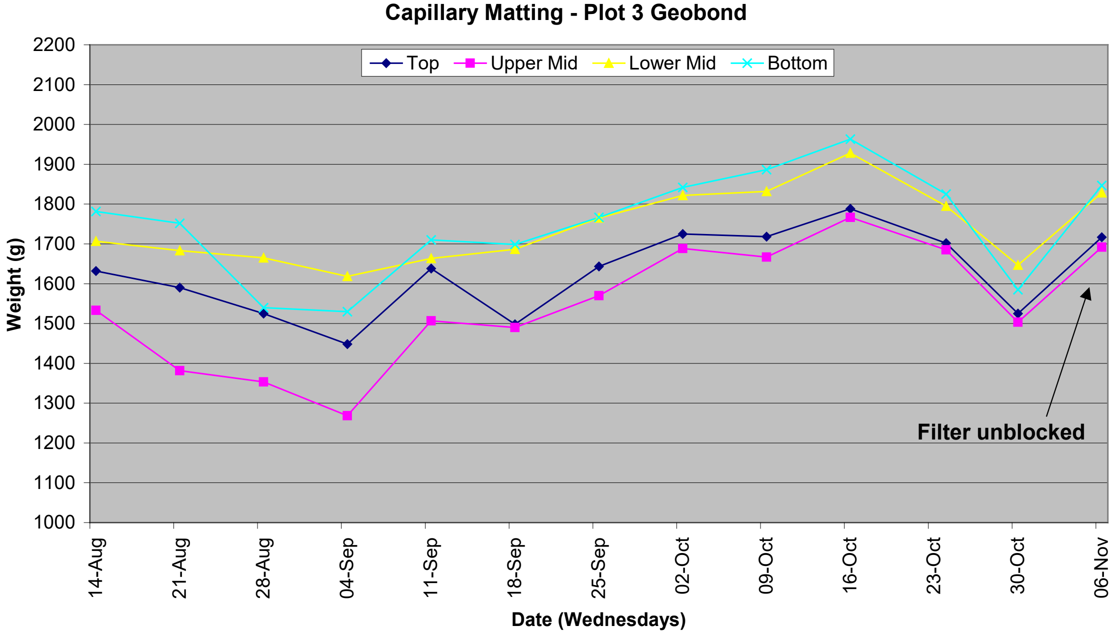
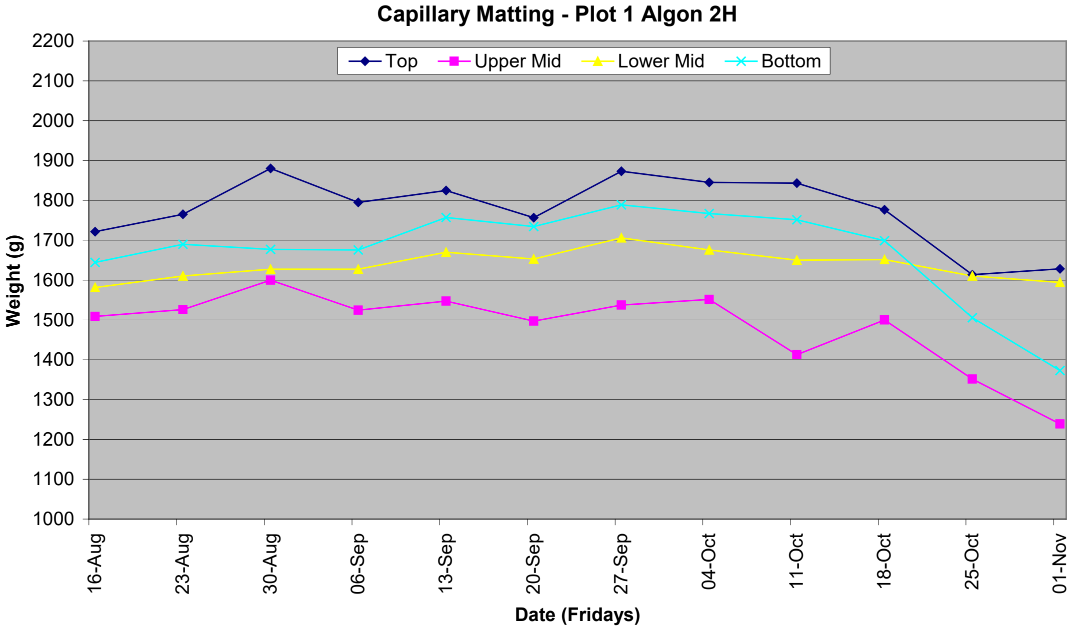
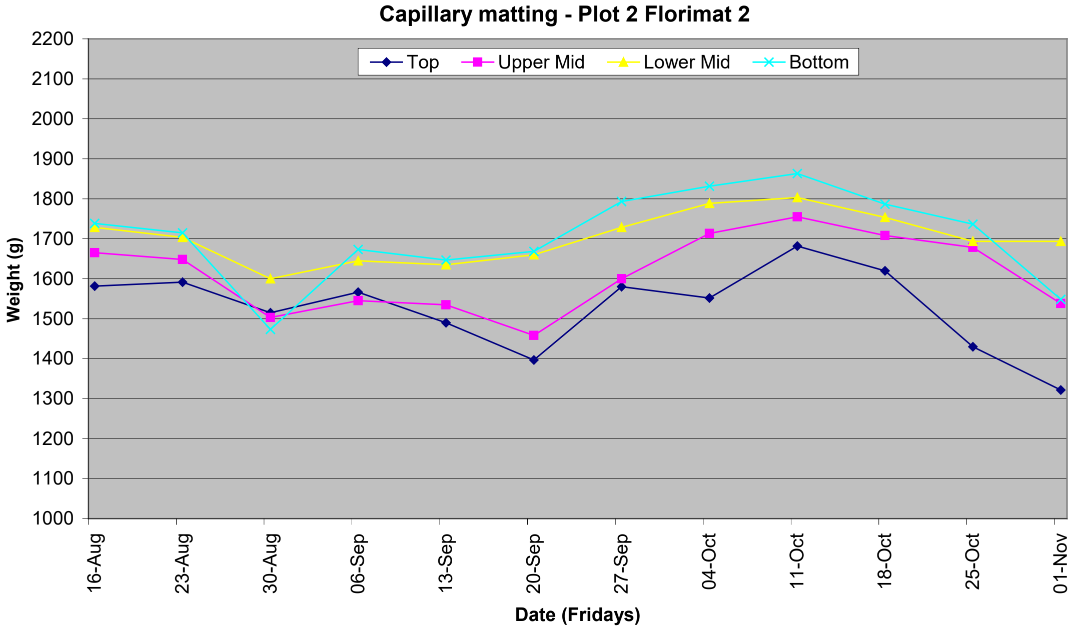
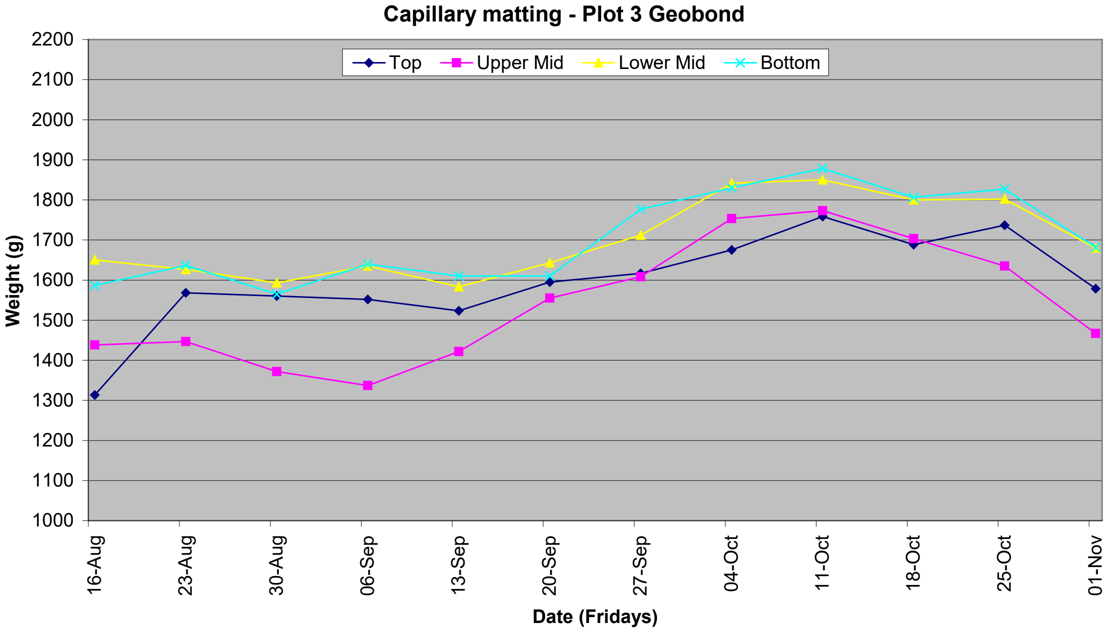

Capillary Matting - Plot 3 Geobond

Figure 7 Capillary matting pot weights over bed - Fridays sample set







Uniformity of water status of between capillary matting, sand bed and overhead systems

Figures 9 – 11 below illustrate the average weights of all sampled containers sampled over the beds, and the standard deviation of their weights (a measure of spread or variation around the mean).

Effect of capillary matting type on water status in containers

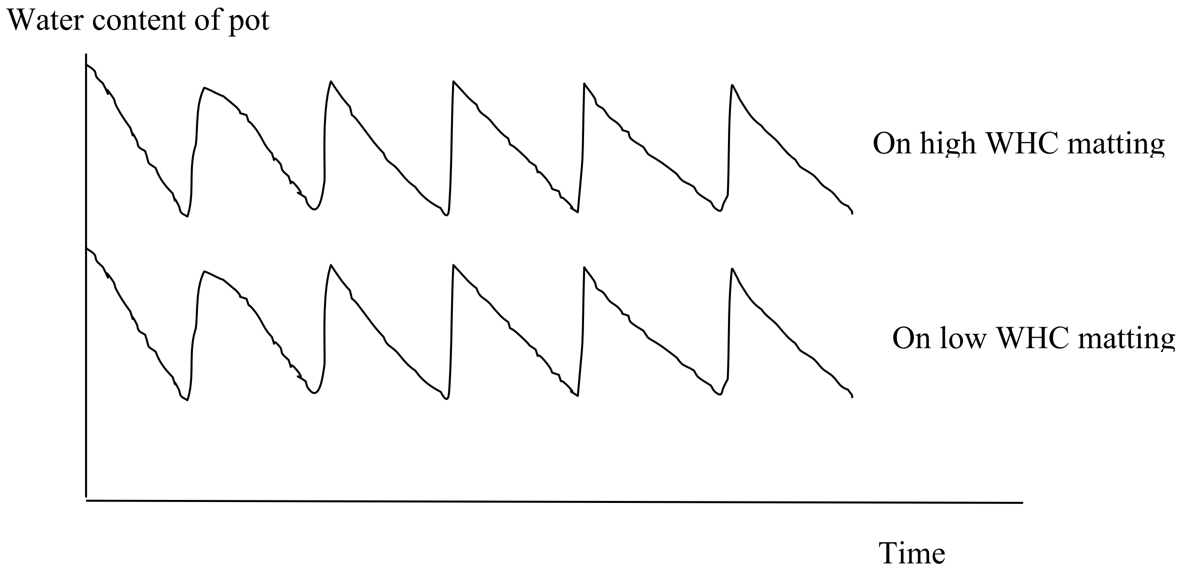
The mean weights for each sample set were quite consistent between the three replicate plots within the sand bed and overhead irrigation systems. Between the three capillary matting plots, there was good consistency between average weights for Geobond and Florimat 2, but containers on the Algon 2H plots were from 100 - 400 g wetter on average, across all three sample sets. If the difference in weight was entirely due to water content of the media rather than bigger plants or more growing media in the pots, this represents an extra 100 - 400 ml of water per 3 litre container.

Total water consumption, as reflected in the time clock settings, or mean consumption, (Figs 1 - 4 above) was broadly similar between the three capillary matting types, particularly in the second half of the experiment. During the experiment, irrigation time clock settings were adjusted in response to the appearance of the plants, and particularly whether there were many plants which were clearly too dry as shown by wilting, or very lightweight pots. Pot weight records were not used formally in this experiment to adjust time clock settings, but instead a 'commercial grower' approach was taken, and adjustments made when required based on crop appearance. In practice, if the crop appeared satisfactory, and little or no hand watering was required, then settings were left alone. Any appreciable runoff, except after hand spot watering, was a good indication that the matting was being run too wet.

Water holding capacity of mattings and its effect on water status

A likely explanation for Algon 2H maintaining wetter containers than either Geobond or Florimat 2 is that it had a higher Water Holding Capacity. Tests carried out early in the project (see Year 1 Annual Report 2000 / 01) gave mean WHC's for 2H, Geobond 300g and Florimat 2 mattings of about 3.2, 1.3 and 2.2 litres / m^2 respectively. Let it be assumed the three mattings receive similar amounts of water, and this brings them back to near their capacity after each irrigation cycle. Also we can assume that the water use by the crop is similar for each matting. The container will absorb water to the point where there is a stable water matrix potential between the matting, and the growing medium in the pot. In an actively growing and transpiring crop, the total capacity of the pot to take up water by capillary action after an irrigation event is likely to exceed the amount available in the matting before the equilibrium point is reached and water uptake stops. Pots on matting with a high WHC, such as Algon 2H, will be able to absorb more water before reaching equilibrium, and thus, on average, be heavier. The water gain and loss fluctuations between irrigation events, and hence water consumption, may be similar even though the mean water status of the containers on different mattings can be different (Fig 8).

Figure 8 Schematic diagram of pots running 'wetter' or 'dryer' while receiving the same irrigation schedule depending on the water holding capacity of the matting type



In this experiment, all the capillary mattings received three irrigation doses per day, and no attempt was made to differentiate between them. In theory, it should be possible to apply the same daily quantity of water in two larger doses per day for the higher WHC Algon matting and have larger wetting and drying fluctuations in the growing medium. I.e. it should have been possible to allow the media to dry down to a similar level to that of pots on Florimat 2 or Geobond before more irrigation was necessary. Experience in Year 2 of this project, however, demonstrated that only a narrow latitude in moisture status of the growing medium was possible before capillarity was broken, irrespective of the type of matting used. Another observation was that while the bonded surface layer of Algon 2H could achieve good contact with the growing medium in the base of the pot, it was necessary to keep the surface of the mat quite moist to maintain capillary contact. As shown in Year 1 of this project, geotextile layers on top of mattings such as Mypex or Tex-R can interfere with maintaining good capillary contact, although this was more problematic with 9 cm pots becoming too lightweight as they dried, than heavier 3 litre containers. Conversely, a layer of Mypex did help prevent exposed areas of the matting between pots from drying out in sunny conditions. Occasionally the matting and edge pots at the exposed north end of the Algon 2H bed did become dry in hot, sunny weather.

A more detailed comparison of how mattings performed under different irrigation timing regimes would have required replicating the facility with more individually controlled plots, and was beyond the scope of this project. Nevertheless, it is likely that the optimum dose and frequency of watering will vary between matting types in a given crop and environment. This is an important aspect of management of crops on capillary mattings but general recommendations cannot be made easily from experiments. Crop managers are in the best position to work out empirically what combination of dose and frequency of watering works best for a given matting and crop in their system set-up.

Figure 9 Mean pot weights (across all positions on bed) for all irrigation systems (lines), and variability statistic, SD (bars) - Mondays sample set

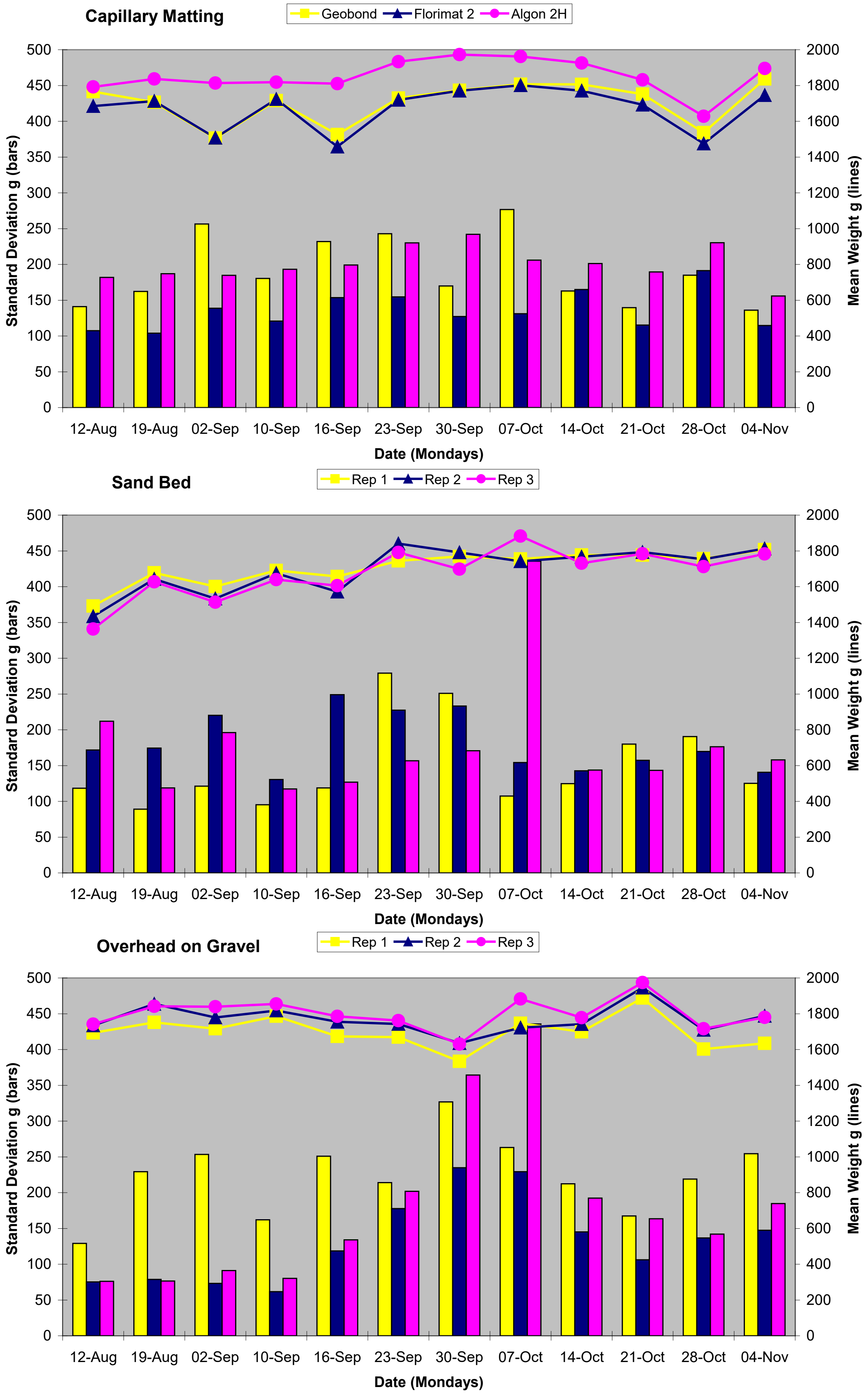


Figure 10 Mean pot weights (across all positions on bed) for all irrigation systems (lines), and variability statistic, SD (bars) - Wednesdays sample set

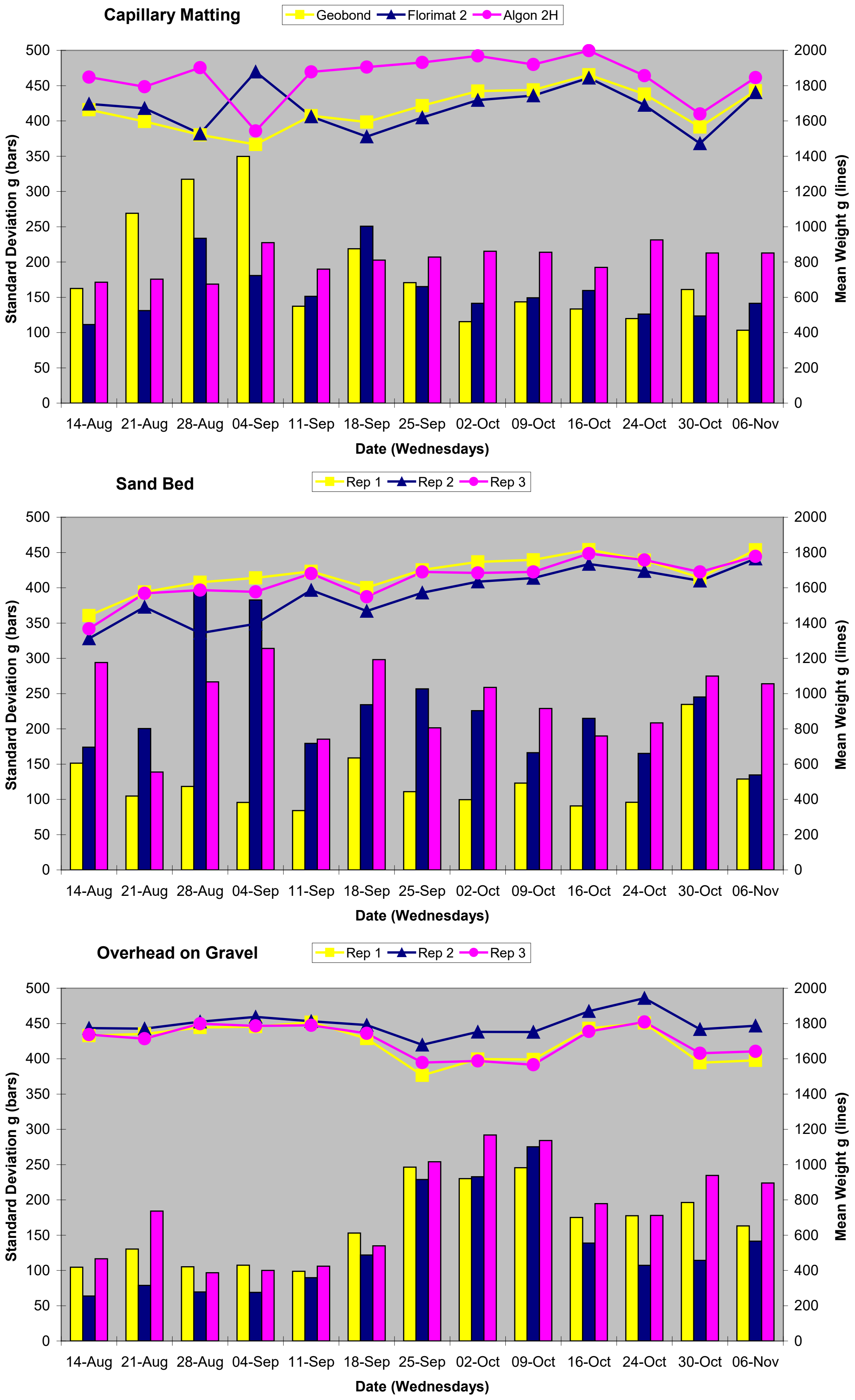
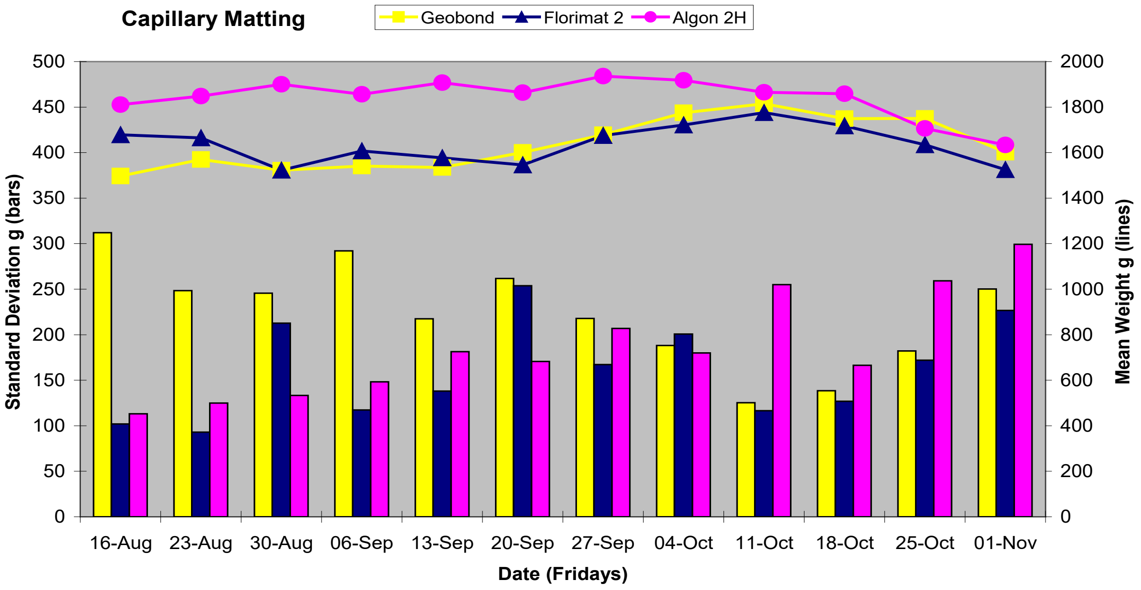
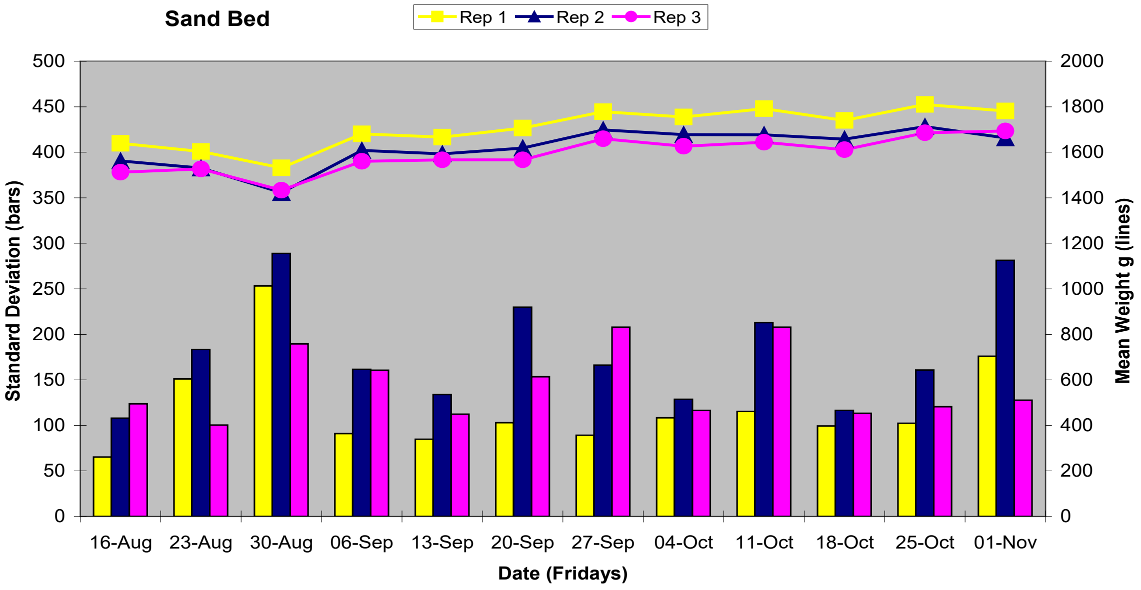
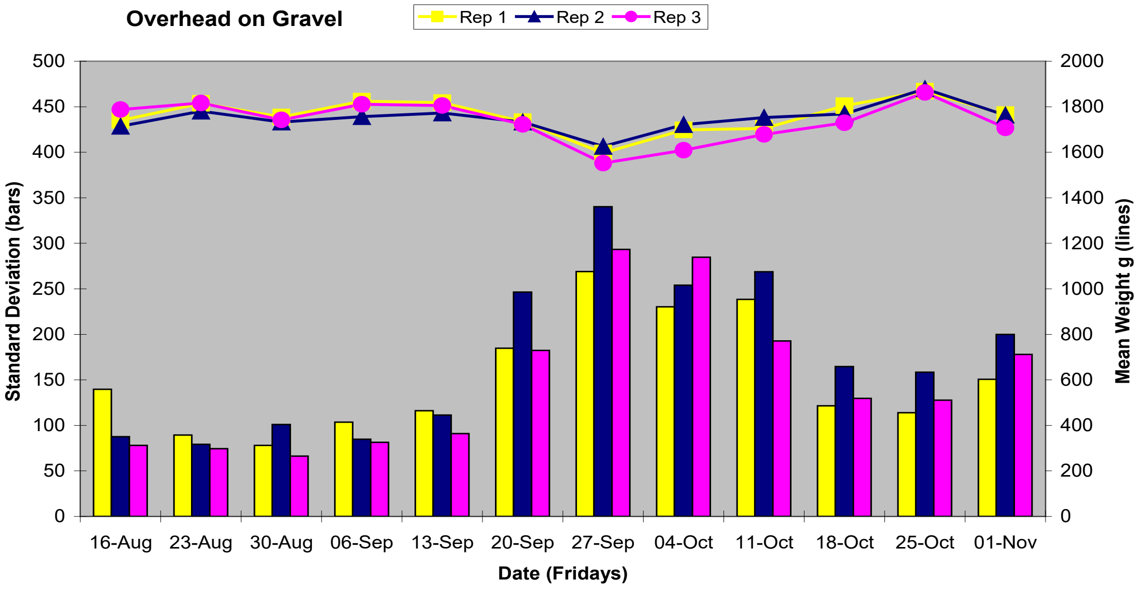


Figure 11 Mean pot weights (across all positions on bed) for all irrigation systems (lines), and variability statistic, SD (bars) - Fridays sample set







Uniformity

The standard deviation bars in Figs 9 – 11 above, show the variation about the mean for the pot weights of those sampled over the bed. Smaller bars indicate greater uniformity.

Data points are from a sample size of 12 values for pot weight. The standard deviation will therefore be sensitive to just one or two abnormally heavy or light pots. When interpreting these data, care should be taken not to overemphasise single data points with abnormally short or tall bars, but rather look at trends over time and across data sets within irrigation systems.

In general, uniformity of pot weights was as good over the capillary matting beds as the sand bed. Interestingly, pot weights with the overhead sprinklers were more uniform than either sub-irrigation system until a four-week period during late September to early October when uniformity across all three sampling sets and replicates on the overhead system was poorer.

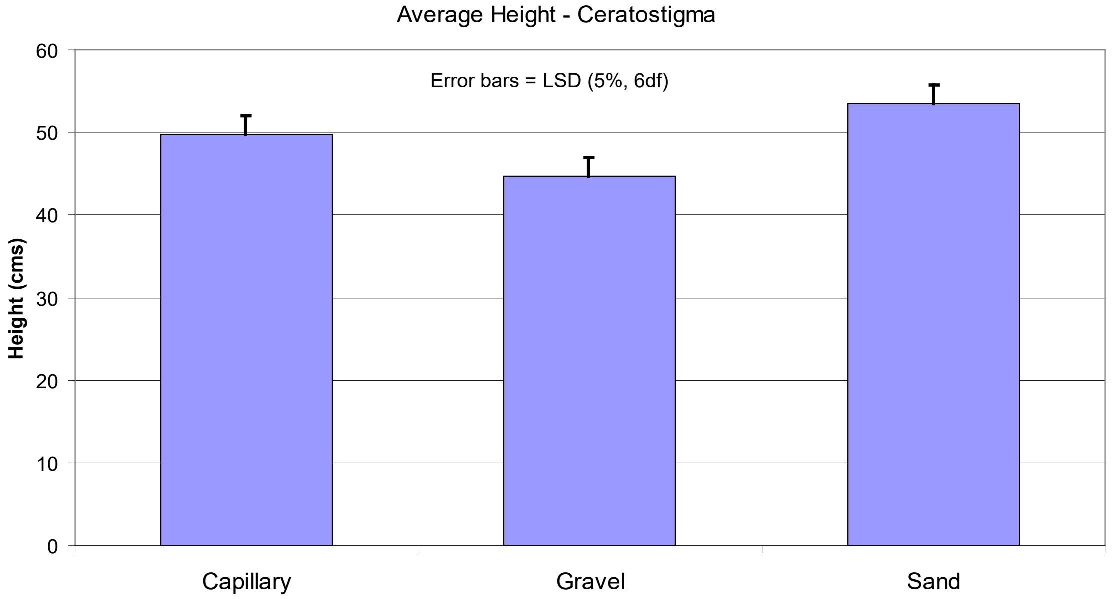
A possible explanation is that with the overhead system, pots were being irrigated to excess early in the experiment. Plant size would have been relatively small after the pruning on 31 July, evapotranspiration less, and heavy watering at each irrigation would have returned most containers to pot capacity, with surplus water from individually 'overwatered' containers draining to waste. Later on as plant size and transpiration increased, irrigations may not have been sufficient to bring all containers back to capacity particularly if the foliage canopy started to interfere with water penetration, and variability between pots would have increased. Time clock settings were reduced for all systems over the course of the experiment as solar radiation and hence evapotranspiration generally declined during from late summer into autumn. It is likely that for the overhead system, settings were reduced too much in mid September in relation to plant growth. From mid October onwards, water loss from the crop would have declined to the extent that the small daily irrigation was sufficient to prevent any pots from getting too dry.

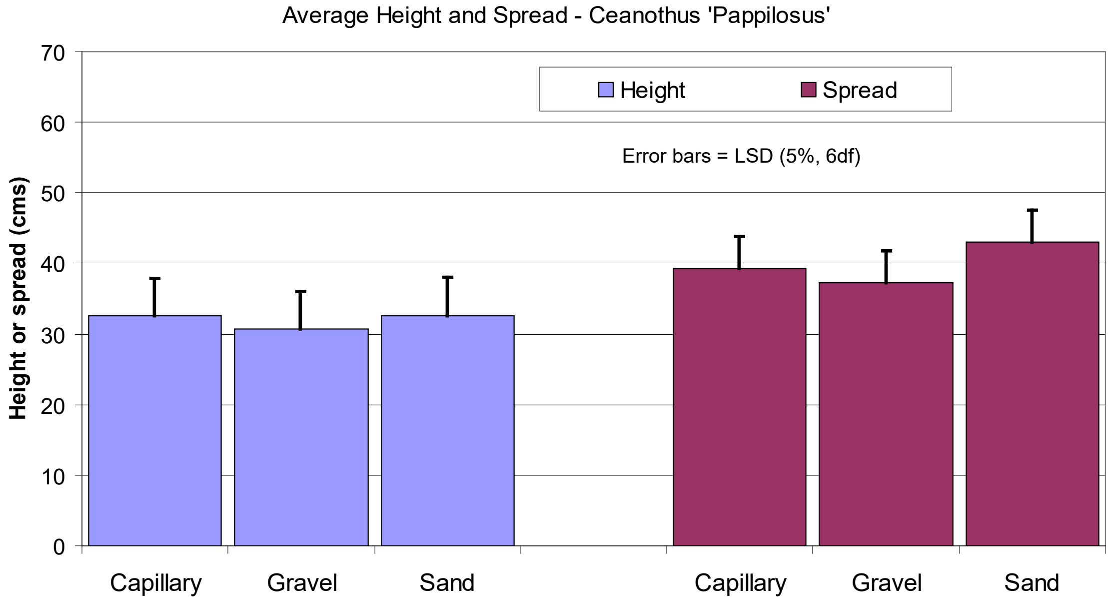
Within the three capillary matting plots, when averaged across all samples throughout the experiment, there was a trend towards slightly more uniform pot weights on Florimat 2 (mean standard deviation 152 g) compared with Algon 2H and Geobond (mean SD 196 g and 199 g respectively).

Plant growth and quality

Figs 12 - 13 below summarise plant growth for species and for each irrigation system. See also Appendix 2, Photos 23 - 41. For the capillary matting system, growth was very similar between matting types. For this analysis the three matting types have thus been treated as three replicates of the same irrigation treatment as for the sand and overhead-on-gravel treatments. At the time of assessment in November, no new growth was present with *Ceratostigma* or *Ceanothus*, but a flush of growth was clearly distinguishable on *Pittosporum* as distinctly paler green leaves. The score for 'bushiness' with *Pittosporum* represents the density of branching within the plant canopy. Growth records for *Ceratostigma* were restricted to a simple height record, as a meaningful spread measurement was impossible due to its straggly, low habit.

Figure 12 Growth of *Ceratostigma* and *Ceanothus* by end of Experiment 1


Average Height - Ceratostigma


Average Height and Spread - Ceanothus 'Pappilosus'

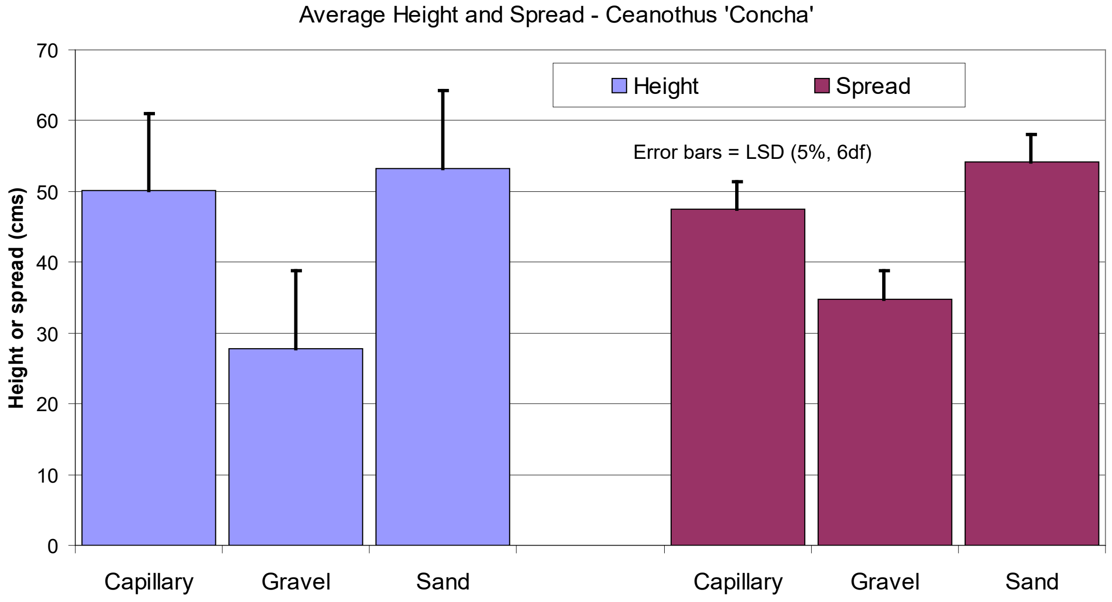
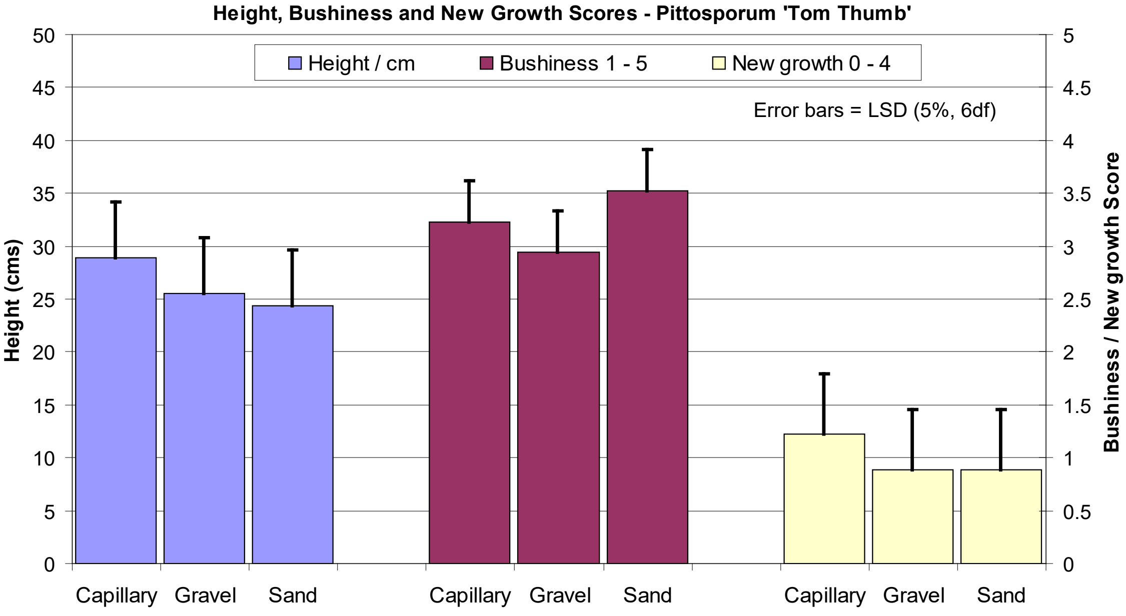
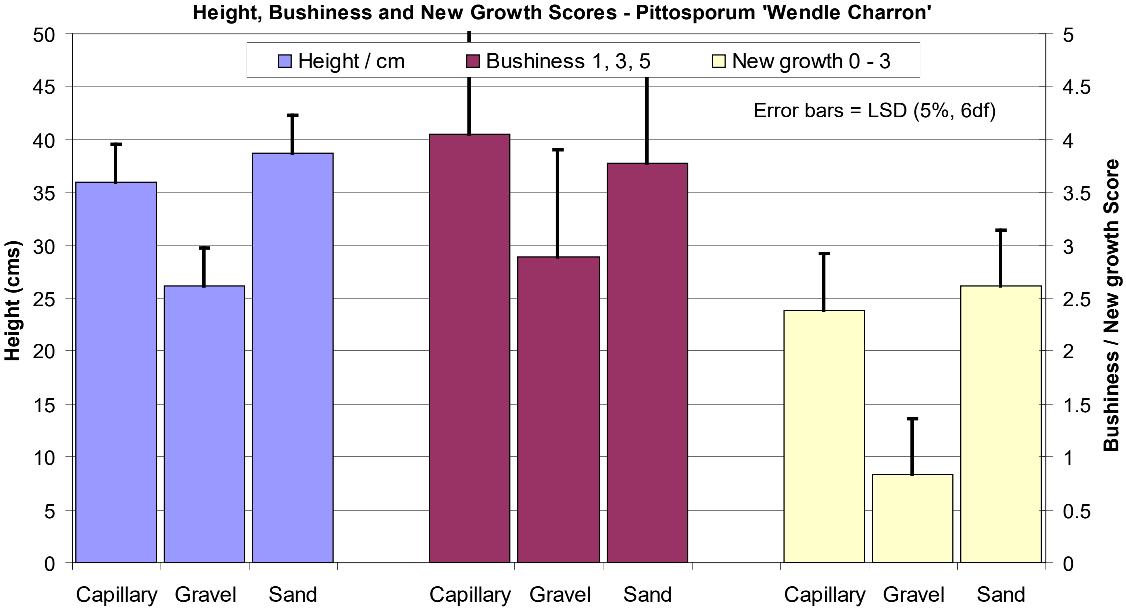
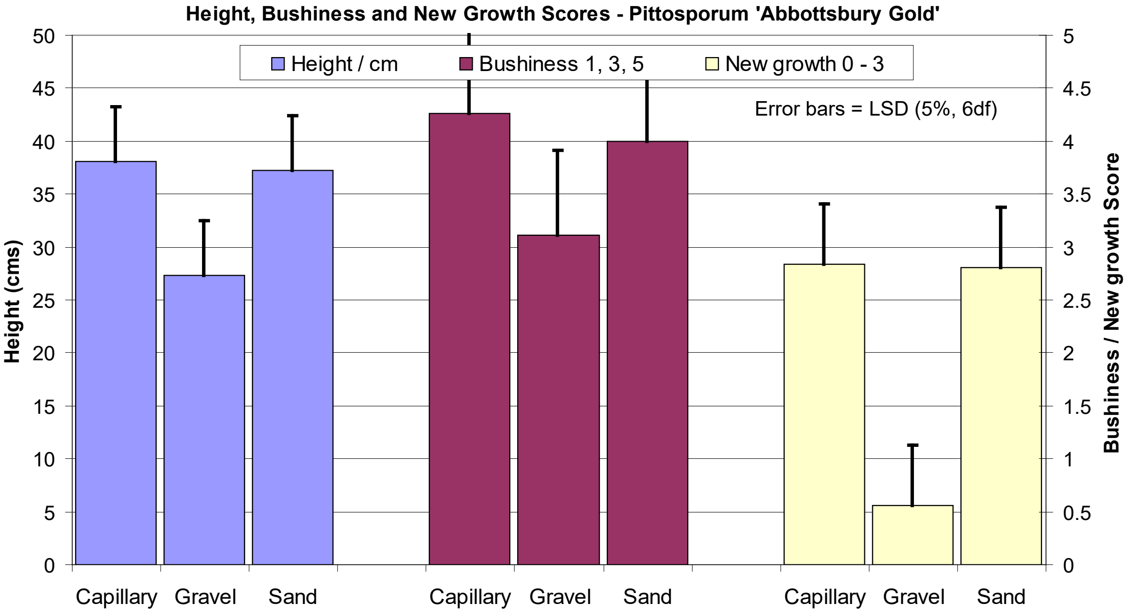

Average Height and Spread - Ceanothus 'Concha'

Figure 13 Growth of *Pittosporum* by end of Experiment 1







Reduced growth with overhead sprinklers

The most visually obvious, and virtually the only significant, growth effect was seen with plants grown under the overhead sprinklers vs. either of the sub-irrigated systems. Both *Pittosporum* 'Wendle Charron' and 'Abbotsbury Gold', and *Ceanothus* 'Concha' were clearly much smaller where grown under the overhead sprinklers. *Ceratostigma griffithii* was also slightly shorter with less vigorous growth.

Pittosporum 'Tom Thumb' was a slightly less vigorous cultivar than the other two *Pittosporum*, and at the time of assessment there was relatively little new growth. Mean height and bushiness scores were also less affected by irrigation treatment. For *P.* 'Wendle Charron' and 'Abbotsbury Gold', however, plant height was significantly shorter, and bushiness significantly less under the overhead sprinklers, and the late flush of growth present on the sub-irrigated plants had been almost totally suppressed here.

The other very clear effect of the overhead sprinkler treatment was the build up of hard water deposits on plant foliage. This was visually most dramatic in all the *Pittosporum* cultivars, and *Ceanothus* 'Concha'. Foliage was much paler from being a lighter green colour, and also due to the build up of white carbonate deposits.

Acidification of the water supply with nitric acid was used for both the sand and capillary matting treatments, following the Year 2 findings that showed hard water deposits could rapidly adversely affect the performance of mattings. It would have been technically difficult to include the overhead sprinklers on the same acidification system, and as most commercial overhead systems do not routinely acidify, it was decided to use untreated mains water for this treatment here. While the presence of hard water deposits is the most likely cause for the reduced growth in the overhead treatment, confounding the irrigation method with the water treatment does make it difficult to strictly compare the effect of irrigation system on plant growth. Benefits of acidifying hard water are well documented, particularly for mist propagation, where the additional low rate nitrogen can enhance growth and foliage colour, and compensate for loss of nitrogen from leaching. Whatever the relative effect of greater leaching, less N supply, and foliage deposits, the growth results here dramatically illustrated the benefits of hard water acidification for improving growth and foliage quality. Effects will be greatest under protection where frequent cycles of foliage wetting and drying will speed up build up of limescale with no benefits of rainfall to help clean the leaves.

Growth on sub-irrigation systems

Both sand and capillary matting beds received the same acidified water supply, so direct comparison here is possible. In most cases there was no significant difference in plant growth or quality between these sub-irrigation treatments.

For the capillary matting beds, growth data for plants towards the top and bottom of the slope was compared, as well as comparisons between matting types. In most cases there was no trend indicating any difference for any of the species. This also applied to the Algon 2H matting, where plants had clearly 'run wetter' than on the other mats. There was an indication that *Pittosporum* 'Wendle Charron' was slightly less bushy and had less new growth than on Florimat 2 or Geobond, but this was not significant, and heights were similar. With *Ceanothus* 'Concha', average height and spread on Algon 2H was marginally greater.

It appears, therefore, that with the range of species used in this experiment, uniformity of plant growth was little affected by the water status variations identified across the bed and between matting types in this project, and that growth on sand and capillary matting beds was equally as good.

'Rooting through'

There was little or no rooting out into the standing base with any of the species except for *Ceratostigma*. Here, there was some appreciable rooting through into the Mypex layer on the sand bed with some plants, and into the gravel on the overhead irrigated plants. There was relatively little rooting through with any of the capillary matting treatments (Appendix 2, Photos 39 - 41).

For the vigorous *Ceratostigma* species, the development of roots through the base of the pot on the gravel and sand species is likely to have been stimulated by its need to search for extra water to top up that being supplied directly to the pots.

It is also important to point out that on inspecting some rootballs of plants at the end of Experiment 1, there was no evidence of root death due to waterlogging, even on pots on the Algon 2H matting which had run wetter than average.

Experiment 2: January - May 2003

The same plants as used in Experiment 1 (except for *Ceratostigma*) were held on the beds with minimal watering, and plants pruned before commencing Experiment 2 in early January 2003. Only the capillary matting beds were used for this experiment, and all were covered with Florimat 2 plus a layer of Mypex 'Red Stripe'. Up to two rows per plot of *Pittosporum* 'Tom Thumb' were removed for commercial sale by the collaborating nursery before the end of the experiment, and remaining plants were re-spaced to fill the allotted bed area. Table 1 summarises the irrigation settings required during the experiment, which ran from w/c 6 January to w/c 26 May.

Table 1 Dates and settings of Water Bugs and Time clocks in Experiment 2

	Water Bug Rep. 1		Water Bug Rep. 3		Time clock Rep. 2	
Date	**Max**	**Min**	**Max**	**Min**	**Total mins/day**	**No. of irrigns/day**
09/01/2003	7	68	7	78	3	2
27/01/2003					6	2
05/02/2003	7	76				
13/03/2003			8	92		
17/03/2003					9	2
14/04/2003	7.5	94	8.2	92		
16/04/2003	8.5	94	9	92	17	2

Irrigation control with time clocks and Water Bugs

Time clock settings were adjusted on just four occasions during the 5-month duration of the experiment. Irrigation control generally appeared to work well despite minimal interference with irrigation settings, and for *Pittosporum* in particular, little hand watering was required. As they grew large in late April and May, however, *Ceanothus* required occasional top up hand watering.

In contrast to early experience reported in the Year 2 Annual Report, the automatic dosing from Water Bugs, used on two of the three plots, was largely trouble-free. It is likely that the larger bed size and improved arrangement of irrigation lines used in Year 3, which generally eased water management, was also a more favourable environment for successful use of the Water Bugs. However, it was still necessary to make minor upward adjustments to the settings, also on four occasions, as water demand increased through the late winter and spring.

Water uptake is dynamic process, and during an irrigation cycle, a significant amount of water is likely to be absorbed by the pot while the T-tape is running, and before the matting has reached its required wetness to switch off the Water Bug. It may be that under conditions of high water demand, a wetter set point is needed to ensure that the water is not turned off prematurely. Alternatively a 'drift' in the calibration or response of the instrument may have occurred that needed adjusting for.

This experiment, as with Experiment 1, has questioned the necessity for very tight and frequent adjustment of irrigation settings according to the weather. This is particularly so with subjects where the aim is to achieve a fast growth rate, in contrast to those where watering must be held back to restrict growth. Also, the limited experience in Experiment 2 does question what advantages there are in using a Water Bug controller over a time clock. They should be able to automatically compensate for moderate changes in irrigation output rate due to fluctuations in water pressure etc. but this was not tested specifically. Theoretically, it should be also possible for them to enable tightly controlled 'dry' regimes such regulated deficit irrigation (RDI) to be imposed on the crop. This would only work if capillary contact could be maintained or readily re-established with an RDI regime, and our experience so far indicates this is not possible or at least difficult with this type of sub-irrigation.

Water use

As expected, the general upward trend for water use by all plots shown in Figure 14, below, follows that for solar radiation in Fig. 15. It is not easy to explain, however, why water use in the time clock plot did not keep pace with the Water Bug plots from about mid March. There were also some large discrepancies in water use between the Water Bug plots during March and early April, until both were adjusted on 14 April, when water use for Plot 1 more than doubled. Interestingly, as in Experiment 1, surplus water runoff from beds occurred very infrequently except where hand watering was applied.

Figure 14 Water use for Experiment 2 (mm irrigation applied per week)

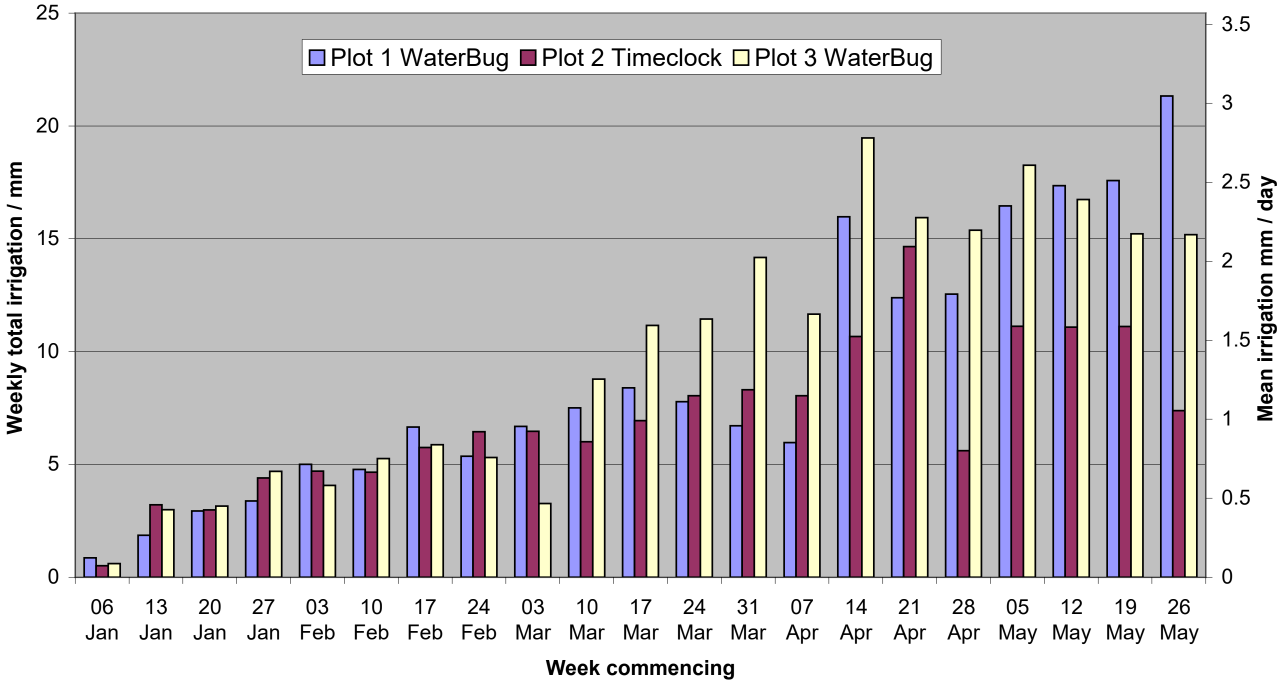
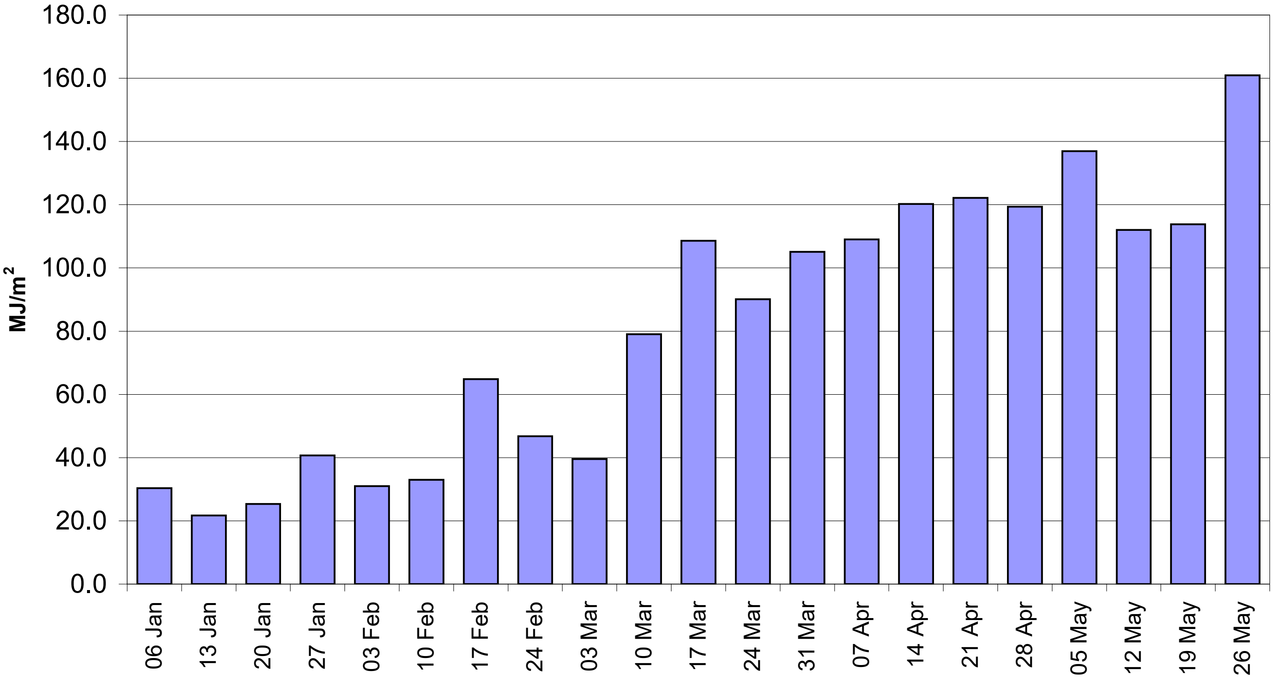


Figure 15 Outdoors solar radiation during Experiment 2 (weekly total MJ/m^2)



Unfortunately it was not possible to extend the monitoring period for Experiment 2 into high summer, which would have given a more stringent test of irrigation control under higher evaporative demand.

Overall water use for the period from 6 January to 30 May averaged 1.3, 1.1 and 1.5 mm / day for Plot 1 (Water Bug), Plot 2 (Time clock) and Plot 3 (Water Bug) respectively.

Visual observation of pot water status

As the primary objective of Experiment 2 was to observe the performance of the Water Bug controller compared to time clocks, no weighing records were carried out. But it was decided to make a rough and ready subjective assessment of each container on one occasion in late May, by visually observing and lifting each container and classifying it as ‘wet’, ‘dry’ or ‘average’. By mapping this record it could give an indication if there was any trend across the beds in pot water content. A diagram of results is shown in Appendix 1, Fig 3. There were slightly more ‘dry’ pots in Plot 3 on the south side of the glasshouse, but otherwise there was no a clear pattern to pot wetness over the beds.

Material prices and economics

Capillary matting is the largest component of the basic material costs for installing a capillary flow bed as illustrated in the following approximation based on 2.5 m wide beds:

	£ / m^2
Capillary matting (e.g. Florimat 2)	1.75
Mypex Red Stripe geotextile layer	0.35
Polythene sheeting base (125 µm)	0.15
T-tape (75 cm spaced lines)	0.12
Timber for sides of bed (22 x 100 mm)	0.75
Levelling sand under base (25 mm depth)	0.30
Total basic materials	**£3.42 / m^2**

Comparable material costs for Efford Drained Sand Beds are about £10 / m^2. Additional costs would include supply connections and fittings for irrigation tubing, drainage link from beds to drainage or recycling infrastructure, solenoid irrigation valves and time clocks, and acid dosing equipment etc.

Some additional matting prices (autumn 2003) were:

	£ / m^2
Flowering Plants - Florimat 2	1.75
Flowering Plants - Florimat 1	1.78
Anglofelt – standard 2H	1.90
Anglofelt – Algon 2H	4.00 (currently supplied mainly to garden centres)
Geobond 300g	1.70 (2002 price - Geobond no longer supplied)

When comparing capillary mattings, allowance should be made for the extra cost of geotextile and base polythene layers needed with some materials.

Acidification of hard water supplies is an extra cost, but worthwhile to maintain performance and reliability of matting irrigation. The extra costs of hand watering hydrophobic patches of beds, and extra rejuvenation treatments of mattings is likely to outweigh the costs of acidification, particularly for protected cropping systems.

CONCLUSIONS

From Final Year

- The experiment confirmed the water savings possible compared to overhead irrigation. Typically this is 25 – 35% of the water use of a well-designed overhead system.
- Water consumption figures were similar to an Efford drained sand bed.
- Once capillary contact was established, plants grew equally well on the sand bed and capillary matting systems. Good capillary lift in the pot was achieved, even with the open textured growing medium used in Year 3 of the project.
- There was some evidence that pot water status varied across the bed with slightly wetter pots at the bottom of the slope, but results were not consistent. Year 2 results that indicated that slight slope of about 2% slope did aid distribution of water from the T-tape lines. Possibly, for use under protection, a slope does not confer any advantages over a level bed. However it would be important to ensure trickle line spacing was close enough to ensure adequate lateral spread of water. Further work would be needed to confirm this, as sloped and level beds were not compared on a semi-commercial scale in this project. Outdoors, a gradient would be necessary to drain surplus rainfall, particularly in winter. In the final analysis, for these species at least, there was no evidence that the differences in water status affected plant growth.
- There was evidence that Algon 2H, a matting with a higher water holding capacity, was maintaining wetter containers than Florimat 2 or Geobond. Again, for the range of subjects tested, there were no discernible differences in plant growth, as a result, and waterlogging or root loss was not observed.
- Uniformity – no better from capillary or sand overall when overhead sprinklers were receiving surplus levels of irrigation, but under high water demand conditions, if pots began to dry out, sub-irrigation systems were more uniform.
- The Water Bug controllers were shown to work as well as time clocks and may be more convenient. However, they did not completely automatically adjust for changes in water demand due to plant growth or season. Adjustments were still required over the period of the experiment.
- While no attempt was made to closely match irrigation scheduling to daily changes in evapotranspirative demand in a formal way, such as was done in LINK project HNS 97, relatively infrequent adjustments were adequate for achieving vigorous growth with these HNS subjects and ‘drying out’ or ‘flooding’ was not a major problem.
- There was no evidence from this project that capillary matting sub-irrigation was able to cope any better than sand beds or overhead sprinklers with a range of subjects with slightly different water demand on the same bed. I.e. controls were set for the majority of plants and occasional extra hand watering applied to top up those with higher demand.
- Generally, capillary matting or sand bed systems force growers to become more aware of water status of pots and manage them more closely to avoid waterlogging or drying out. There is less scope to waste water with capillary irrigation, as waterlogging of pots will be

evident from over watering. With overhead systems, wastage of water from over irrigating will be less obvious if the growing media and the standing base is freely drained.

- Capillary matting types – Algon 2H, Florimat 2 and Geobond are all capable of giving good results on this system, however it is best to adjust irrigation settings accordingly.
- Overhead irrigation under protection using non-acidified hard water can leave heavy deposits on foliage and significantly reduce growth.
- Spacing of irrigation lines is important. A maximum 0.75 m is advisable even where a slope across the bed is used.

Conclusions from previous Years

- Capillary mattings need to have both adequate water holding capacity, and capillary lift ability in order to laterally move water from trickle lines to pots, and to maintain a capillary link with the growing medium between irrigation cycles. A range of mattings can give good results provided they are managed appropriately. It is not possible, therefore, to define optimum specifications but only provide broad guidelines. For use as a primary irrigation system, mattings will typically be at least 2 – 3 mm thick, and have a WHC of at least 1 litre / m^2 and a vertical capillary lift of at least 40 mm. Mattings based on both natural fibres (e.g. wool / cotton) and synthetic fibres can give good results.
- Mattings need full wetting up at each watering to miximise effective and rapid uptake into containers. However presence of run-off is a good indication that matting is being run too wet.
- Maintaining capillary contact between the growing medium and matting is essential for success with this watering system. Once capillarity with a few pots is lost, water status over the bed becomes increasingly variable. Thoroughly rewetting by hand is then normally necessary to restore capillary contact.
- Achieving wide latitudes of growing medium wetness (ie ‘dry’ regimes or wide wet / dry cycles) difficult to achieve where capillary matting used as a primary irrigation system.
- For best results as a primary irrigation system, beds need a properly prepared base that remains smooth and firm. Mattings will redistribute water from with slight bumps or hollows in the bed surface (e.g. about 1 cm), but tolerance to larger irregularities was not tested.
- Hard water deposits can rapidly build up on mattings used under protection and this will cause them to become water repellent and restrict the spread of water.

Appendix 1

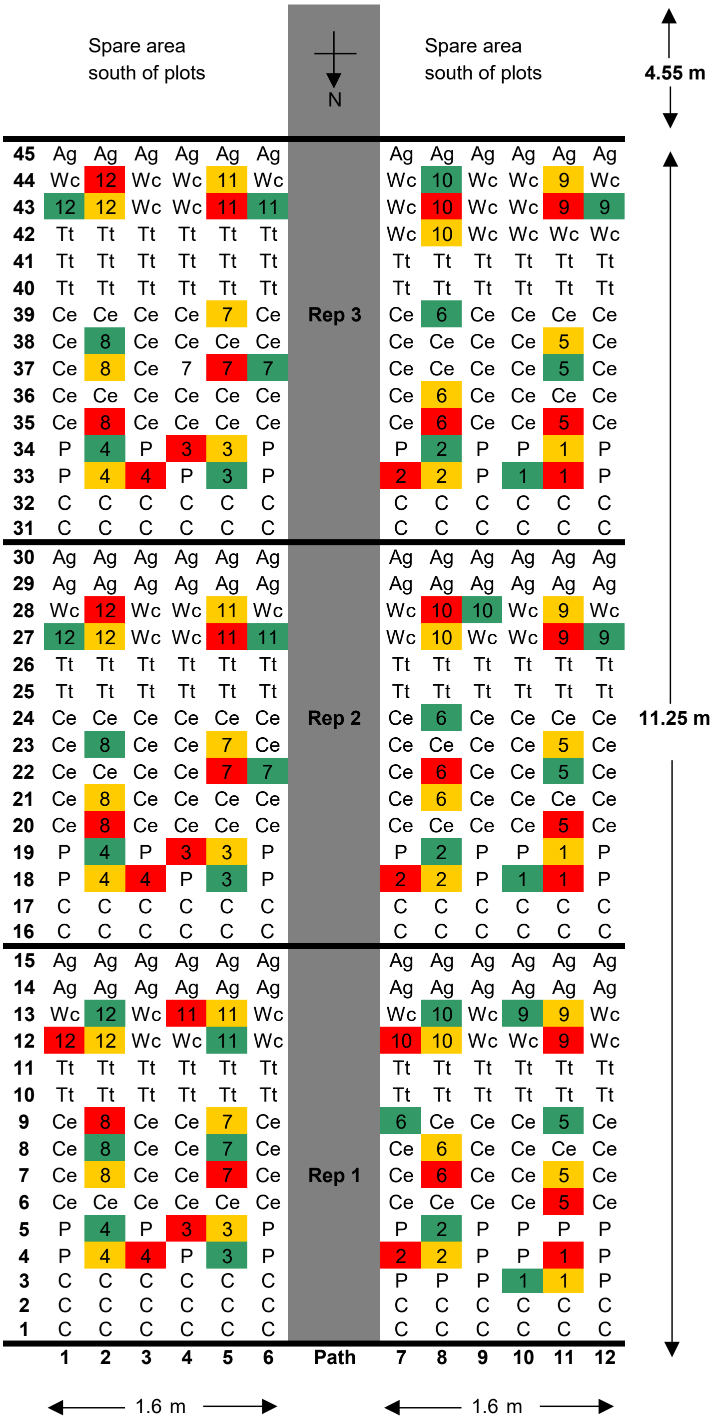
Experiment 1 and 2 treatment plans

Appx. 1 Fig 1. Experiment 1 Layout and sampled plants for weight records

Sand Bed and Overhead on Gravel Beds (identical layout)

Pots spaced 25cm apart. (Mypex squares are 25cm)

🟨 **Monday Records**
🟥 **Wednesday records**
🟩 **Friday records**



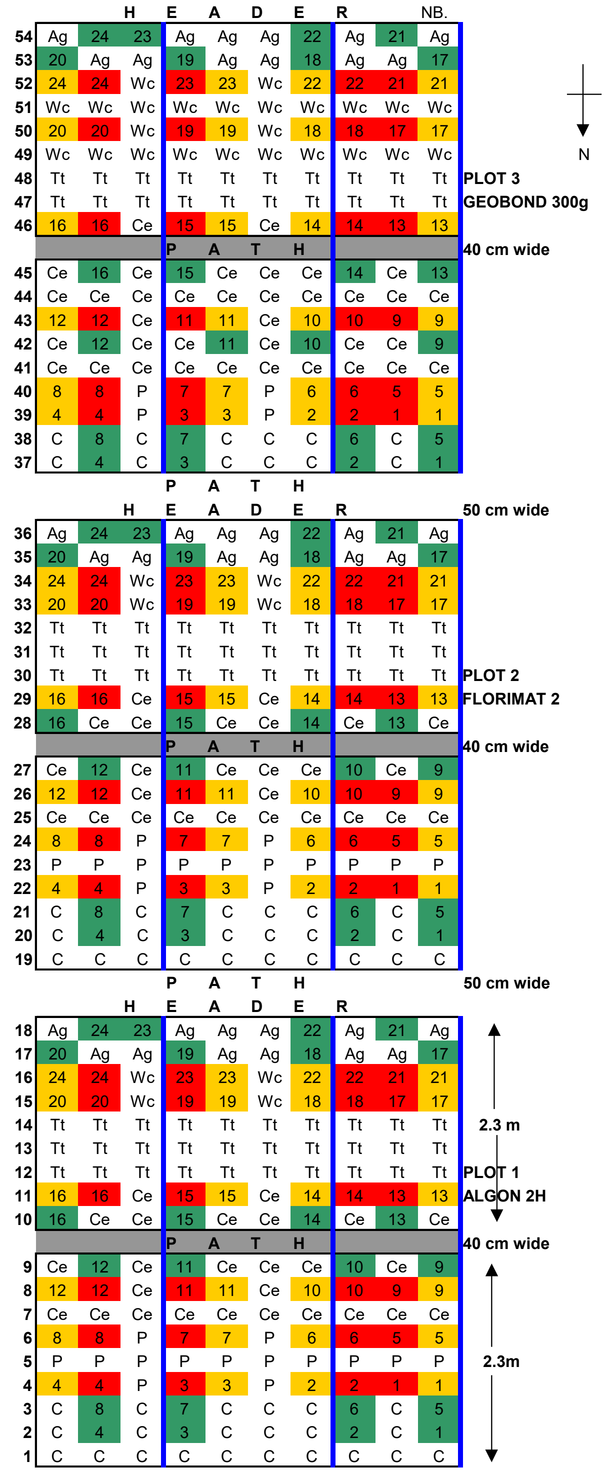
45	Ag	Ag	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag	Ag	Ag
44	Wc	12	Wc	Wc	11	Wc		Wc	10	Wc	Wc	9	Wc
43	12	12	Wc	Wc	11	11		Wc	10	Wc	Wc	9	9
42	Tt	Tt	Tt	Tt	Tt	Tt		Wc	10	Wc	Wc	Wc	Wc
41	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
40	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
39	Ce	Ce	Ce	Ce	7	Ce	**Rep 3**	Ce	6	Ce	Ce	Ce	Ce
38	Ce	8	Ce	Ce	Ce	Ce		Ce	Ce	Ce	Ce	5	Ce
37	Ce	8	Ce	7	7	7		Ce	Ce	Ce	Ce	5	Ce
36	Ce	Ce	Ce	Ce	Ce	Ce		Ce	6	Ce	Ce	Ce	Ce
35	Ce	8	Ce	Ce	Ce	Ce		Ce	6	Ce	Ce	5	Ce
34	P	4	P	3	3	P		P	2	P	P	1	P
33	P	4	4	P	3	P		2	2	P	1	1	P
32	C	C	C	C	C	C		C	C	C	C	C	C
31	C	C	C	C	C	C		C	C	C	C	C	C
30	Ag	Ag	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag	Ag	Ag
29	Ag	Ag	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag	Ag	Ag
28	Wc	12	Wc	Wc	11	Wc		Wc	10	10	Wc	9	Wc
27	12	12	Wc	Wc	11	11		Wc	10	Wc	Wc	9	9
26	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
25	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
24	Ce	Ce	Ce	Ce	Ce	Ce	**Rep 2**	Ce	6	Ce	Ce	Ce	Ce
23	Ce	8	Ce	Ce	7	Ce		Ce	Ce	Ce	Ce	5	Ce
22	Ce	Ce	Ce	Ce	7	7		Ce	6	Ce	Ce	5	Ce
21	Ce	8	Ce	Ce	Ce	Ce		Ce	6	Ce	Ce	Ce	Ce
20	Ce	8	Ce	Ce	Ce	Ce		Ce	Ce	Ce	Ce	5	Ce
19	P	4	P	3	3	P		P	2	P	P	1	P
18	P	4	4	P	3	P		2	2	P	1	1	P
17	C	C	C	C	C	C		C	C	C	C	C	C
16	C	C	C	C	C	C		C	C	C	C	C	C
15	Ag	Ag	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag	Ag	Ag
14	Ag	Ag	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag	Ag	Ag
13	Wc	12	Wc	11	11	Wc		Wc	10	Wc	9	9	Wc
12	12	12	Wc	Wc	11	Wc		10	10	Wc	Wc	9	Wc
11	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
10	Tt	Tt	Tt	Tt	Tt	Tt		Tt	Tt	Tt	Tt	Tt	Tt
9	Ce	8	Ce	Ce	7	Ce		6	Ce	Ce	Ce	5	Ce
8	Ce	8	Ce	Ce	7	Ce		Ce	6	Ce	Ce	Ce	Ce
7	Ce	8	Ce	Ce	7	Ce	**Rep 1**	Ce	6	Ce	Ce	5	Ce
6	Ce	Ce	Ce	Ce	Ce	Ce		Ce	Ce	Ce	Ce	5	Ce
5	P	4	P	3	3	P		P	2	P	P	P	P
4	P	4	4	P	3	P		2	2	P	P	1	P
3	C	C	C	C	C	C		P	P	P	1	1	P
2	C	C	C	C	C	C		C	C	C	C	C	C
1	C	C	C	C	C	C		C	C	C	C	C	C
	1	**2**	**3**	**4**	**5**	**6**	**Path**	**7**	**8**	**9**	**10**	**11**	**12**

Species:
C & P = Ceanothus 'Concha' and 'Pappilosus'
Ce = Ceratostigma griffithii
Tt, Wc & Ag = Pittosporum 'Tom Thumb', 'Wendle Charron' and 'Abbotsbury Golc

Capillary Bed

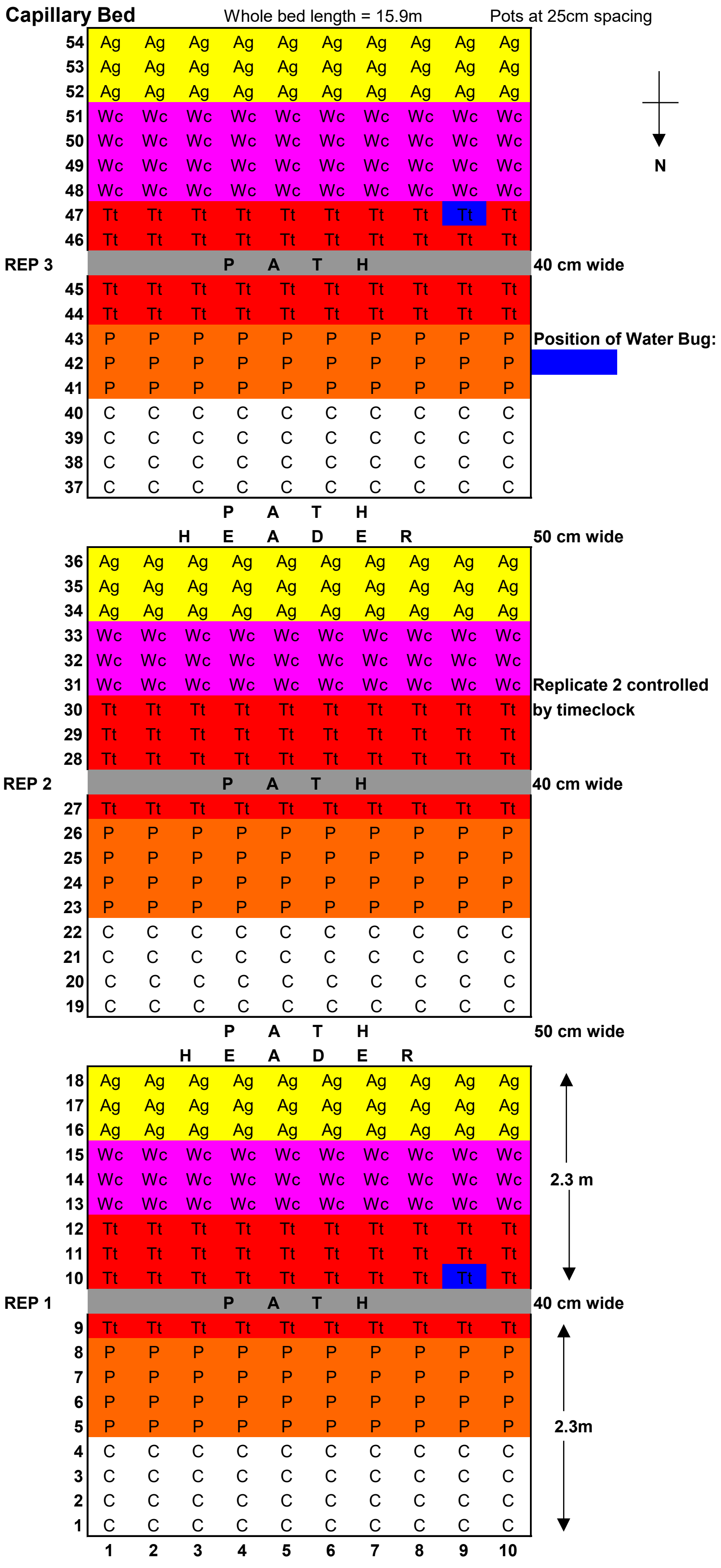
Whole bed length = 15.9m

Pots at 25cm spacing



			H	**E**	**A**	**D**	**E**	**R**		NB.	
54	Ag	24	23	Ag	Ag	Ag	22	Ag	21	Ag	
53	20	Ag	Ag	19	Ag	Ag	18	Ag	Ag	17	
52	24	24	Wc	23	23	Wc	22	22	21	21	
51	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
50	20	20	Wc	19	19	Wc	18	18	17	17	
49	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	N
48	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**PLOT 3**
47	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**GEOBOND 300g**
46	16	16	Ce	15	15	Ce	14	14	13	13	
				P	**A**	**T**	**H**				**40 cm wide**
45	Ce	16	Ce	15	Ce	Ce	Ce	14	Ce	13	
44	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	
43	12	12	Ce	11	11	Ce	10	10	9	9	
42	Ce	12	Ce	Ce	11	Ce	10	Ce	Ce	9	
41	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	
40	8	8	P	7	7	P	6	6	5	5	
39	4	4	P	3	3	P	2	2	1	1	
38	C	8	C	7	C	C	C	6	C	5	
37	C	4	C	3	C	C	C	2	C	1	
				P	**A**	**T**	**H**				
			H	**E**	**A**	**D**	**E**	**R**			**50 cm wide**
36	Ag	24	23	Ag	Ag	Ag	22	Ag	21	Ag	
35	20	Ag	Ag	19	Ag	Ag	18	Ag	Ag	17	
34	24	24	Wc	23	23	Wc	22	22	21	21	
33	20	20	Wc	19	19	Wc	18	18	17	17	
32	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
31	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
30	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**PLOT 2**
29	16	16	Ce	15	15	Ce	14	14	13	13	**FLORIMAT 2**
28	16	Ce	Ce	15	Ce	Ce	14	Ce	13	Ce	
				P	**A**	**T**	**H**				**40 cm wide**
27	Ce	12	Ce	11	Ce	Ce	Ce	10	Ce	9	
26	12	12	Ce	11	11	Ce	10	10	9	9	
25	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	
24	8	8	P	7	7	P	6	6	5	5	
23	P	P	P	P	P	P	P	P	P	P	
22	4	4	P	3	3	P	2	2	1	1	
21	C	8	C	7	C	C	C	6	C	5	
20	C	4	C	3	C	C	C	2	C	1	
19	C	C	C	C	C	C	C	C	C	C	
				P	**A**	**T**	**H**				**50 cm wide**
			H	**E**	**A**	**D**	**E**	**R**			
18	Ag	24	23	Ag	Ag	Ag	22	Ag	21	Ag	
17	20	Ag	Ag	19	Ag	Ag	18	Ag	Ag	17	
16	24	24	Wc	23	23	Wc	22	22	21	21	
15	20	20	Wc	19	19	Wc	18	18	17	17	
14	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**2.3 m**
13	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
12	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**PLOT 1**
11	16	16	Ce	15	15	Ce	14	14	13	13	**ALGON 2H**
10	16	Ce	Ce	15	Ce	Ce	14	Ce	13	Ce	
				P	**A**	**T**	**H**				**40 cm wide**
9	Ce	12	Ce	11	Ce	Ce	Ce	10	Ce	9	
8	12	12	Ce	11	11	Ce	10	10	9	9	
7	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	Ce	
6	8	8	P	7	7	P	6	6	5	5	
5	P	P	P	P	P	P	P	P	P	P	**2.3m**
4	4	4	P	3	3	P	2	2	1	1	
3	C	8	C	7	C	C	C	6	C	5	
2	C	4	C	3	C	C	C	2	C	1	
1	C	C	C	C	C	C	C	C	C	C	

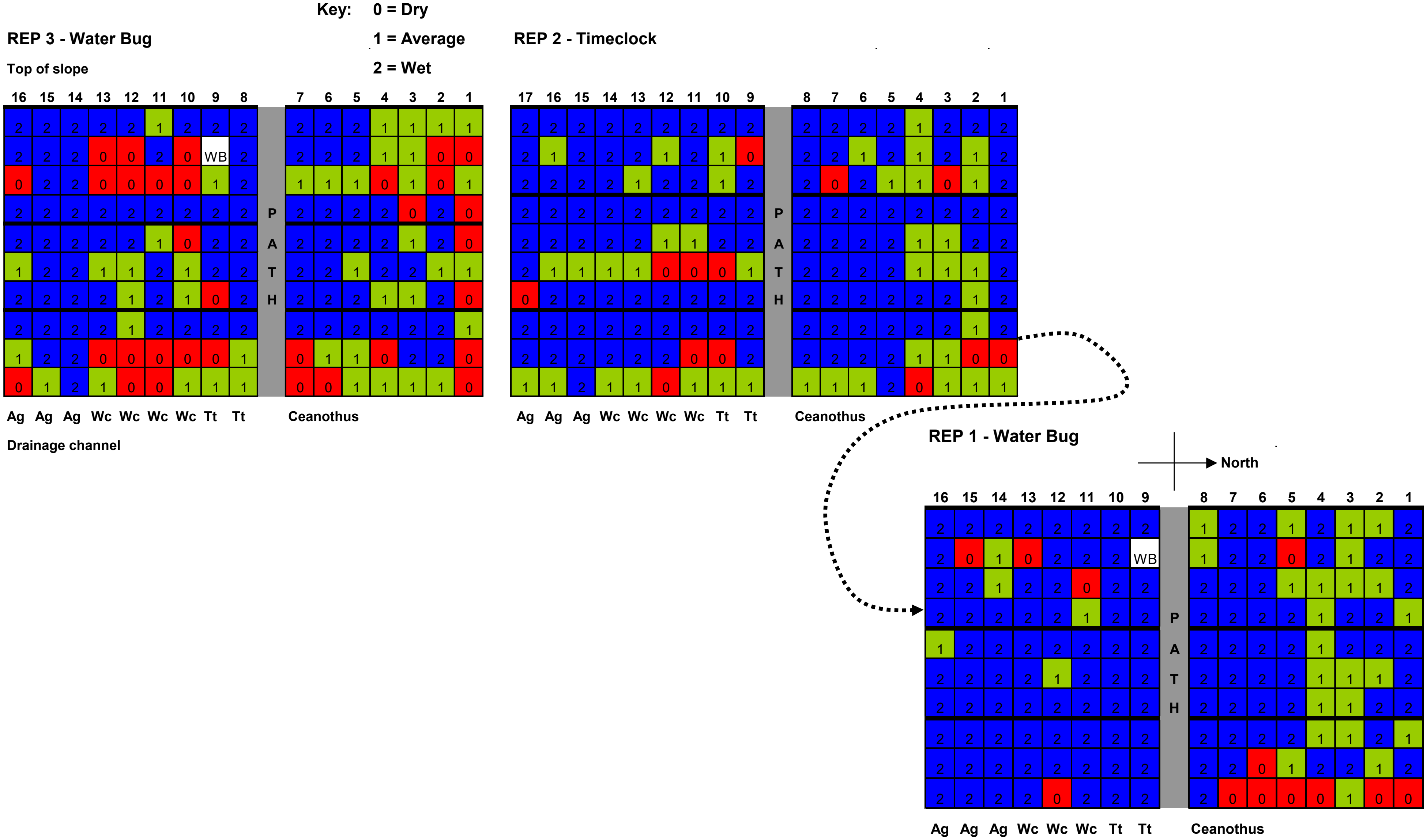
Appx. 1 Fig 2. Experiment 2 layout - Capillary bed with Florimat 2 + Mypex ‘Red Stripe’ only



Capillary Bed Whole bed length = 15.9m Pots at 25cm spacing

54	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
53	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
52	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
51	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
50	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
49	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
48	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
47	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt 🟦	Tt	
46	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
REP 3				**P**	**A**	**T**	**H**				**40 cm wide**
45	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
44	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
43	P	P	P	P	P	P	P	P	P	P	**Position of Water Bug:**
42	P	P	P	P	P	P	P	P	P	P	🟦
41	P	P	P	P	P	P	P	P	P	P	
40	C	C	C	C	C	C	C	C	C	C	
39	C	C	C	C	C	C	C	C	C	C	
38	C	C	C	C	C	C	C	C	C	C	
37	C	C	C	C	C	C	C	C	C	C	
				P	**A**	**T**	**H**				
			H	**E**	**A**	**D**	**E**	**R**			**50 cm wide**
36	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
35	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
34	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
33	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
32	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
31	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	**Replicate 2 controlled**
30	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	**by timeclock**
29	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
28	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
REP 2				**P**	**A**	**T**	**H**				**40 cm wide**
27	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
26	P	P	P	P	P	P	P	P	P	P	
25	P	P	P	P	P	P	P	P	P	P	
24	P	P	P	P	P	P	P	P	P	P	
23	P	P	P	P	P	P	P	P	P	P	
22	C	C	C	C	C	C	C	C	C	C	
21	C	C	C	C	C	C	C	C	C	C	
20	C	C	C	C	C	C	C	C	C	C	
19	C	C	C	C	C	C	C	C	C	C	
				P	**A**	**T**	**H**				**50 cm wide**
			H	**E**	**A**	**D**	**E**	**R**			
18	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
17	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
16	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	Ag	
15	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
14	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	**2.3 m**
13	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	Wc	
12	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
11	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
10	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt 🟦	Tt	
REP 1				**P**	**A**	**T**	**H**				**40 cm wide**
9	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	Tt	
8	P	P	P	P	P	P	P	P	P	P	
7	P	P	P	P	P	P	P	P	P	P	
6	P	P	P	P	P	P	P	P	P	P	
5	P	P	P	P	P	P	P	P	P	P	**2.3m**
4	C	C	C	C	C	C	C	C	C	C	
3	C	C	C	C	C	C	C	C	C	C	
2	C	C	C	C	C	C	C	C	C	C	
1	C	C	C	C	C	C	C	C	C	C	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	

Appx. 1 Fig 3. Experiment 2 - Subjective assessment of 'Dry', 'Wet' and 'Average' pots carried out in late May 2003



Key:
0 = Dry
1 = Average
2 = Wet

REP 3 - Water Bug

Top of slope

16	15	14	13	12	11	10	9	8		7	6	5	4	3	2	1
2	2	2	2	2	1	2	2	2		2	2	2	1	1	1	1
2	2	2	0	0	2	0	WB	2		2	2	2	1	1	0	0
0	2	2	0	0	0	0	1	2		1	1	1	0	1	0	1
2	2	2	2	2	2	2	2	2	P	2	2	2	2	0	2	0
2	2	2	2	2	1	0	2	2	A	2	2	2	2	1	2	0
1	2	2	1	1	2	1	2	2	T	2	2	1	2	2	1	1
2	2	2	2	1	2	1	0	2	H	2	2	2	1	1	2	0
2	2	2	2	1	2	2	2	2		2	2	2	2	2	2	1
1	2	2	0	0	0	0	0	1		0	1	1	0	2	2	0
0	1	2	1	0	0	1	1	1		0	0	1	1	1	1	0
Ag	Ag	Ag	Wc	Wc	Wc	Wc	Tt	Tt		Ceanothus						

Drainage channel

REP 2 - Timeclock

17	16	15	14	13	12	11	10	9		8	7	6	5	4	3	2	1
2	2	2	2	2	2	2	2	2		2	2	2	2	1	2	2	2
2	1	2	2	2	1	2	1	0		2	2	1	2	1	2	1	2
2	2	2	2	1	2	2	1	2		2	0	2	1	1	0	1	2
2	2	2	2	2	2	2	2	2	P	2	2	2	2	2	2	2	2
2	2	2	2	2	1	1	2	2	A	2	2	2	2	1	1	2	2
2	1	1	1	1	0	0	0	1	T	2	2	2	2	1	1	1	2
0	2	2	2	2	2	2	2	2	H	2	2	2	2	2	2	1	2
2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	1	2
2	2	2	2	2	2	0	0	2		2	2	2	2	1	1	0	0
1	1	2	1	1	0	1	1	1		1	1	1	2	0	1	1	1
Ag	Ag	Ag	Wc	Wc	Wc	Wc	Tt	Tt		Ceanothus							

REP 1 - Water Bug

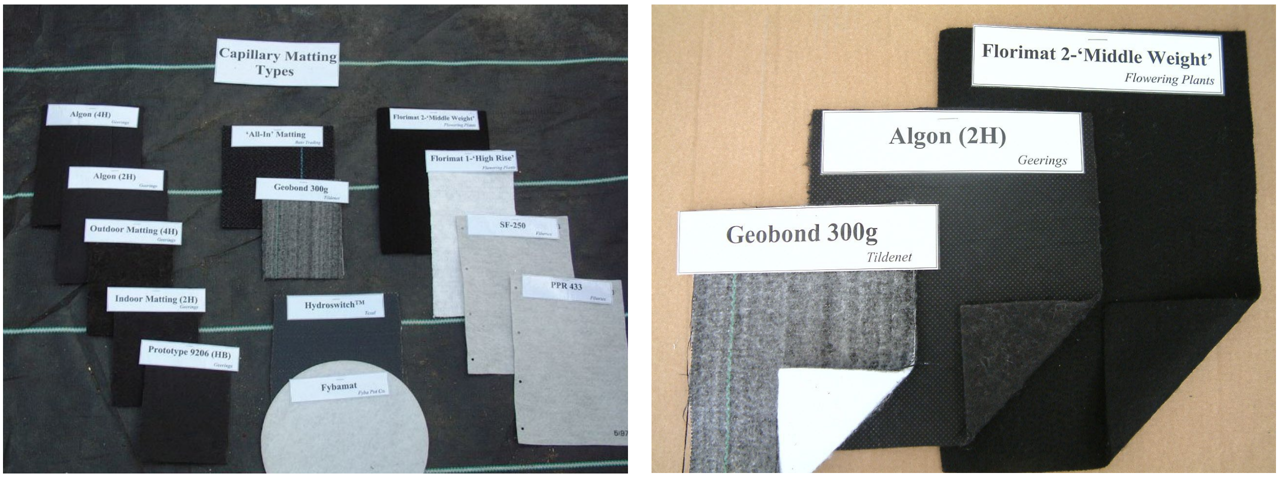
North

16	15	14	13	12	11	10	9		8	7	6	5	4	3	2	1
2	2	2	2	2	2	2	2		1	2	2	1	2	1	1	2
2	0	1	0	2	2	2	WB		1	2	2	0	2	1	2	2
2	2	1	2	2	0	2	2		2	2	2	1	1	1	1	2
2	2	2	2	2	1	2	2	P	2	2	2	2	1	2	2	1
1	2	2	2	2	2	2	2	A	2	2	2	2	1	2	2	2
2	2	2	2	1	2	2	2	T	2	2	2	2	1	1	1	2
2	2	2	2	2	2	2	2	H	2	2	2	2	1	1	2	2
2	2	2	2	2	2	2	2		2	2	2	2	1	1	2	1
2	2	2	2	2	2	2	2		2	2	0	1	2	2	1	2
2	2	2	2	0	2	2	2		2	0	0	0	0	1	0	0
Ag	Ag	Ag	Wc	Wc	Wc	Tt	Tt		Ceanothus							

Appendix 2

Photographs

Photos 1 – 2. A range of matting materials used in this project (left), and the three mattings used in Year 3 (right).



Photos 3 – 4. Year 1 experiments. Comparison of materials for capillary lift (left) and examining influence of Mypex and Tex R covers on capillary contact (right).

Photos 5 – 6. Small-scale beds used for testing sloped capillary flow irrigation.

Photos 7 – 8. Good capillary contact with base (left) vs poor capillary contact after turning plant out of pot (right).

Photos 9 – 10. Construction of larger scale capillary flow beds. Creating 50 mm drop across the bed and a drainage channel.

Photos 11 – 12. Filling and firming a smooth surface layer with sand.

Photos 13 – 15. Laying polythene base layer (left), Experiment 2 plots with Florimat 2 and Mypex 'Red Stripe' (centre), and arrangement of three lines of T-tape offset up the slope with covered drain at the bottom (right).

Photos 16 – 17. Acidifying unit (left) and Water Bug in use during Experiment 2 (right).

Photos 18 – 19. Beds at start of Experiment 1. Overhead sprinklers on gravel base (left), drained sand bed (right), 8 August 2002.

Photo 20. Capillary flow bed, 8 August 2002.

Photos 21 - 22. Experiment 2, re-growth on capillary matting beds by 8 May 2003. Top, *Pittosporum* spp. ('Abbotsbury Gold', 'Wendle Charron' and 'Tom Thumb', l to r). Bottom, *Ceanothus* spp. ('Pappilosus' and 'Concha', l to r).

Photos 23 - 28 Plant assessment at end of Experiment 1, autumn 2002.
Typical plants from Capillary Matting, Overhead on Gravel and Sand Bed (l to r).

Pittosporum 'Abbotsbury Gold'

Pittosporum 'Tom Thumb'

Pittosporum 'Wendle Charron'

Ceratostigma griffithii

Photos 23 - 28 (cont.). Capillary Matting, Overhead on Gravel and Sand Bed (l to r).

Ceanothus ‘Concha’

Ceanothus ‘Pappilosus’

Photo 29. Bushiness scores 5 – 1 *Pittosporum* ‘Tom Thumb’.

Photo 30. New Growth scores 3 – 0 *Pittosporum* ‘Abbotsbury Gold’.

Photos 31 - 38. Colour of sub-irrigated plants using acidified water (left) vs. overhead irrigated with no acidification causing hard water deposits (right).

Pittosporum 'Abbotsbury Gold'

Ceanothus 'Concha'

Ceanothus 'Pappilosus'

Pittosporum 'Tom Thumb'

Photos 39 - 41. ***Ceratostigma griffithii p*****lants showing maximum levels of 'rooting through' observed for each irrigation system.**

Capillary matting

Overhead on gravel

Sand bed