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Key workers:	Mr C M Burgess, Project Leader (author of report) Mr T Clench, Scientific Support Mr P Newnham, Site Engineering Supervisor Mr K Tarrant, Engineering Support
Location:	Horticulture Research International Efford Lymington Hampshire SO41 0LZ Tel: 01590 673341 Fax: 01590 671553
Project co-ordinators:	Mr John Woodhead, Hilliers Nurseries Ltd Mr John Adlam, Dove Associates
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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

Special Note - HDC and HRI are aware that though the findings of this work, using European recognised standard tests, have given consistent results, these do differ from statements and figures obtained by various manufacturers and suppliers. Whilst standing by the figures obtained, which show differences between products, HDC recommend that potential purchasers of such products consult manufacturers and suppliers and test trial materials on their nursery before using this report to make final purchasing decisions.

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PRACTICAL SECTION FOR GROWERS

Background and objectives

The use of capillary matting irrigation under protection, although widely used for pot and bedding plants grown on benches, is not yet widely used for container grown nursery stock. It has potential to increase the efficiency of water use by both reducing the amount of water applied (e.g. compared with overhead sprinkler systems), and by improving uniformity of water distribution. Capillary sand beds, such as the Efford sand bed, have been well proven over many years, but are relatively expensive to install. The majority of nursery stock growers still use overhead systems. The proportion of nursery stock grown under protection for some period during the production cycle continues to increase. There is considerable commercial potential, therefore, if cost-effective methods of irrigating nursery stock using capillary matting as an alternative to sand-beds, for example, can be developed. Recent progress in a HortLINK project on controlling plant growth with controlled water stress, and current advances in electronic control technology for irrigation are other factors that make capillary irrigation attractive.

There are a large number of capillary matting products on the market, but very little objective comparison information is available or standard methods for assessing their properties for horticultural use.

The objective of the first year of this project was to assess and further develop some standard methods of comparing capillary matting materials used in horticulture. Also to start to investigate how they may best be used for irrigation of container nursery stock under protection. In particular, to test matting types and specifications for a ‘capillary flow bed system’ for nursery stock. The capillary flow bed concept originated from Geisenheim Research Station, Germany, and, with further development, has potential for nursery stock production in the UK.

Summary of Results and Conclusions

Stage 1 - Physical characteristics of mattings

In the first stage of the project, eleven mattings were tested for their key physical characteristics of:

1 Water holding capacity (WHC) expressed as litres/m^2
2 Vertical capillary lift expressed as cm

The testing procedures used were based on the DIN standards typically quoted in supplier’s data. The following summarises the main findings:

- There were several significant discrepancies between manufacturer's values and ours (see table below).
- It was difficult to observe and measure vertical capillary rise accurately, particularly with dark materials.
- There was an approximate relationship between these key characteristics. Mattings with a high WHC tended to have low capillary rise and vice versa.
- Despite the limitations of these tests in evaluating the performance of mattings in a horticultural context, they provide relatively simple and rapid tests for initially evaluating the potential of materials.

Summary comparison of data from matting manufacturers and Efford

	WHC litres/m^2		Vertical lift/cm	
Matting type	**Manufacturer**	**Efford***	**Manufacturer**	**Efford**
2H 5848	3.5	3.14	n/a	1.58
4H 5850	7.0	5.55	2.0	1.82
HB 9206	n/a	0.66	7.0	3.14
Geobond 300g	0.36**	1.34	n/a	N/a
Bato All-In mat	n/a	2.78	n/a	N/a
Florimat 1	1.3	1.57	13.4	7.14
Florimat 2	4.7	2.17	10.5	2.06
SF 250	1.7	2.98	7.0	3.78
PPR 433	0.8	1.13	8.0	6.30
Hydroswitch	n/a	3.25	5.0	N/a
Fybamat	4.0	n/a	4.0	N/a

* Mean of values tested Nov 2000 & July 2001
** Stated to BS 3449:1990, not DIN standard

Stage 2 - Movement of water between mattings and containers

The aim of this stage was to develop a standard method that would test both water distribution laterally through the mat, but also the delivery of water from the matting up into the pot. This took into account the interface between the base of the pot and the matting, where clearly capillary contact must be maintained to move water into the medium.

Test beds in a glasshouse compartment were constructed capable of supporting an array of peat filled containers on top of the matting samples. The beds incorporated an adjustable slope so that the ability of the mat to supply water to containers by capillary action against an incline could be tested. A constant level of water was maintained in a gutter at the base of the slope, and the weights of containers under increasing capillary tension at intervals up the slope were assessed. 3 litre and 9 cm pots filled with a peat, but without plants, were used. A series of experiments took place between October 2000 and February 2001.

- Drying out of pots from pot capacity, to reach their equilibrium weights, was slow over the winter period. The method showed some merit as a standard procedure, but would be more practical if carried out under spring – autumn conditions.
- Adding a top layer of Mypex or Tex-R to mattings that did not incorporate a 'geotextile' in their construction, had a marked effect on the ability to maintain capillary contact between the container and the matting. 9 cm pots were more adversely affected than 3 litre containers because of their lighter weight. Integral mattings, such as Geobond and All-In mattings maintained better capillary contact.
- Mattings which exhibited the highest capillary lift in laboratory tests did not consistently demonstrate better ability to supply water to containers against a slope in the glasshouse test.

Stage 3 - Development of the capillary flow bed

One of the final objectives of the project, is to develop the 'capillary flow bed' as a practical automated irrigation and growing system for HNS under protection. The first step was to build a prototype rig to get some experience with the basic principles. Then to build a series of small-scale test beds to carry out experiments on the influence of different slopes, test working tolerances of different matting types to imperfections in the bed profile ('bumps and hollows'), and to compare mattings for their water use and distribution over the bed. The principle of a capillary flow bed is that water is supplied to the matting, via trickle tubing, along the upper edge of the bed incorporating a gentle (e.g. 2%) slope. Gravity and capillary action should then combine to help maintain an even distribution of water over the bed, and disperse excess water if required.

- A small 1.2 m x 2.4 m prototype bed was constructed and was successful in maintaining reasonably uniform and consistent irrigation to a dense crop of Hydrangea over a three month period. Irrigation controlled by a time clock was adjusted manually.

- An array of 8 similar beds was then constructed in preparation for future work in Year 2. These will incorporate sensors to automatically control irrigation and enable experiments to be conducted under standard and controlled conditions.

Future work in Year 2 will also include the construction of a larger semi-commercial scale bed in a large polythene tunnel, for comparison with other conventional irrigation including overhead.

Action points for growers

The project to date has largely been involved in making preliminary assessments of capillary matting characteristics and developing assessment techniques and a prototype capillary flow bed. It is therefore premature to recommend specific products or methods of use. However, the following points can be made:

- DIN standards provide a rapid and relatively simple method of assessing two important physical characteristics of matting materials, namely their water holding capacity (WHC) and vertical capillary lift. However, the interpretation of this data in a horticultural context is not straightforward. In addition, results so far have shown some discrepancies with published figures.

- Ground cover materials may be an important component in the production systems in helping to maintain a clean, weed free bed surface for containers, however, tests have shown that their use in connection with capillary mattings can reduce the capillary matting's ability to maintain capillary contact with growing media. This will be a greater problem with smaller, lighter pots than, for example, 3 litre pots. Mattings, which integrate a 'geotextile' layer in their construction, may perform better, but further tests are necessary before recommendations can be made.

SCIENCE SECTION

Introduction

The use of capillary matting irrigation under protection, although widely used for pot and bedding plants grown on benches, is not yet widely used for container grown nursery stock. It has potential to increase the efficiency of water use by both reducing the amount of water applied (e.g. compared with overhead sprinkler systems), and by improving uniformity of water distribution.

Uniformity of water status between containers is important in maintaining uniformity of growth and quality within the crop. A range of problems can occur with poor irrigation distribution. For example, a large proportion of the crop may be over watered with overhead irrigation systems just to ensure 'dryer edges' and 'corners' are adequately watered. At best, over watering causes leaching of nutrients and wastes water, at worst it leads to root loss, disease and plant losses. Obviously severe under watering can lead to permanent wilting and plant death, but will restrict growth if not optimal. The practical difficulties involved in attempting to restore a uniform water status to a crop which has a number of badly dried out containers is well known, with repeated hand watering required before growing media becomes hydrophilic again. Finally, to hand water uniformly and with minimal waste, requires experience and skill, and it is an expensive operation.

Efford sand beds, developed in the 1970's, were proven to provide exceptionally uniform irrigation with benefits for enhanced winter drainage. However, they require carefully graded level sites, skilled construction and a significant capital investment for proper installation. Capillary matting has traditionally been used on smooth and level glasshouse benching systems for irrigation of relatively small containers. Its use as a standing base on the ground for nursery stock, has typically been as a secondary irrigation aid to help redistribute surplus overhead applied water to the base of pots, rather than as complete sub irrigation system. Its use outside has also been of limited success on level or uneven surfaces, particularly in winter, because of problems of water logging.

The proportion of container nursery stock that now spends at least part of the production cycle under protection continues to increase. In addition, there are a number of capillary mattings now available on the market, which claim to have good water holding, and / or capillary lift characteristics, but there has been no independent research to investigate their properties. Several of these mattings incorporate an easily cleanable and hardwearing 'geotextile' layer on top, which should make them suitable for standing out container plants. Finally, some work in Germany has indicated some potential for a gently sloping 'capillary flow bed' system for nursery stock. This has stimulated work through this project to:

1 Identify and develop standard testing procedures for capillary matting to enable matting types to be compared for their efficacy to supply water to containers.

2 Develop and test the 'capillary flow bed' system under protection for uniform automatic or semi-automatic irrigation of container nursery stock.

This first annual report covers the preliminary investigations into properties of a range of matting products, the development of a technique to assess capillary lift into containers, and the preliminary experiment with a prototype test rig to develop the capillary flow bed system.

PART 1 - PHYSICAL CHARACTERISTICS OF MATERIALS

Samples of the following mattings were collected during the first year of the project for testing.

Table 1 Capillary matting types included in Year 1 of project

Supplier	Type	Composition
Geerings	Indoor Matting (2H)	Wool based. Black
	Outdoor Matting (4H)	Wool based. Black
	Prototype 9206 (HB)	Cotton based. Black
Tildenet	Geobond 300 g	Synthetic / wool blend. White but with bonded black geotextile top layer
Bato Trading	'All-In' matting	Synthetic. Incorporates geotextile top layer and impermeable base layer. Black
Flowering Plants	Florimat 1 – 'High Rise'	Synthetic. White
	Florimat 2 – 'Middle weight'	Synthetic. Black
Fibertex	SF-250	Synthetic. (Polypropylene / Polyester /
	PPR 433	Viscose blends). Both types grey
Texel	Hydroswitch™	Synthetic. Incorporates perforated polythene top layer. Black
Fyba Pot Co.	Fybamat	Synthetic (polyester). White

Two key characteristics of materials for use in horticulture as capillary matting are its water holding capacity (WHC) and capillary lift.

The water holding capacity gives an indication of the volume of water per unit area that the matting could hold when wetted to 'field capacity' in a horizontal position. This should clearly be related to the amount of water available for sub-irrigating containers between irrigation cycles. The capillary rise is an indication of the mat's ability to move water upwards against gravity. This is normally expressed in terms of vertical capillary lift. Capillary mattings are obviously used in a horizontal or near horizontal position in horticulture as a standing base! Nevertheless, the capillary lift of the mat would be expected to have some relation to its ability to redistribute water throughout the mat from the point of application (e.g. by trickle or drip lines).

In addition, capillary action is necessary to prevent excessive drainage of the mat on a slight slope, or maintain a good water distribution over a bed surface with minor ‘hollows and bumps’.

Table 2 Data from manufacturers’ literature

Matting type	Dry weight g/m^2	WHC litres/m^2	Vertical lift/cm
2H 5848	250	3.5	n/a
4H 5850	464	7.0	2.0
HB 9206	250	n/a	7.0
Geobond 300g	456	0.36*	n/a
Bato All-In mat	n/a	n/a	n/a
Florimat 1	180	1.3	13.4
Florimat 2	250	4.7	10.5
SF 250	250	1.7	7.0
PPR 433	150	0.8	8.0
Hydroswitch	n/a	n/a	5.0
Fybamat	170	4.0	4.0

*Stated to BS 3449 : 1990

Standard DIN tests for materials

Several manufacturers referred to two DIN standards for textiles, written in 1968:
DIN 53 923 ‘Determination of water absorption of textile fabrics’
DIN 53 924 ‘Velocity of suction of textile fabrics in respect of water (method by determining the rising height)’

These (German) standards were designed for fabrics in general, and not specifically for capillary fabrics for horticultural use. However, they are a recognised industrial standard. We based our initial assessments for WHC and vertical capillary rise on these procedures.

Water holding capacity (WHC)

Method

Pieces of new matting 100 mm x 100 mm were cut. Five replicates of each matting type were used.
Each piece was weighed when dry. Each piece was then immersed in a bowl of distilled water for 60 seconds while being agitated to eliminate trapped air. It was then removed and laid on a horizontally supported gauze to drain freely for a period of 120 seconds, and immediately transferred to scales and reweighed.

The WHC was calculated as:

$$W_w - W_d \times 100 = ml / m^2$$

Where W_w and W_d were weights of wet and dry matting respectively, in grammes.

Results

Table 3. Water holding capacity (litres/m²) measured at Efford - Nov 2000

	Matting type						
Replicate	**2H**	**4H**	**HB**	**SF 250**	**PPR 433**	**Flori 1**	**Flori 2**
1	2.820	5.030	0.570	3.060	1.120	1.640	2.310
2	3.440	5.050	0.680	3.060	1.160	1.570	1.990
3	3.240	4.830	0.680	3.220	1.140	1.590	2.140
4	3.050	5.250	0.640	2.960	1.070	1.500	2.100
5	3.430	5.400	0.700	3.270	1.150	1.890	2.220
Mean	**3.196**	**5.112**	**0.654**	**3.114**	**1.128**	**1.638**	**2.152**
SE	0.1181	0.0980	0.0232	0.0571	0.0159	0.0669	0.0542

Only the matting ranges from Flowering Plants, Geerings and Fibertex were available for inclusion in the initial tests. A repeat test for water holding capacity was carried out in July 2001, which incorporated some other mats (Table 4). The repeat tests for the first set of mattings agreed well with the first results. Our value of 1.3 litres/m^2 for Geobond was much larger than Tildenet's quoted value carried out using a different standard (BS 3449).

Table 4. Water holding capacity (litres/m²) measured at Efford - July 2001

	Matting type						
Replicate	**2H**	**4H**	**HB**	**SF 250**	**PPR 433**	**Flori 1**	**Flori 2**
1	3.033	5.887	0.496	3.034	-	1.489	1.981
2	2.816	6.376	0.693	2.770	-	1.566	2.159
3	3.294	6.464	1.038	2.963	-	1.498	2.206
4	2.980	5.778	0.508	2.737	-	1.481	2.265
5	3.121	5.415	0.572	2.713	-	1.501	2.294
Mean	**3.049**	**5.984**	**0.661**	**2.843**	**n/a**	**1.506**	**2.181**
SE	0.0789	0.1949	0.1004	0.0649	-	0.0152	0.0552
	Geobond	**Hydro-switch**	**All-In**	**Fyba**			
1	0.911	2.950	2.869	-			
2	1.070	3.045	2.688	-			
3	0.922	3.325	2.784	-			
4	1.627	3.584	2.834	-			
5	2.184	3.368	2.738	-			
Mean	**1.343**	**3.254**	**2.783**	**n/a**			
SE	0.2476	0.1147	0.0324	-			

Vertical capillary lift

Method

Strips of new matting 250 mm x 30 mm were cut using 5 replicates per matting type. All the mattings were non-woven, and therefore should not have had a 'warp' or 'weft' direction such that their orientation might affect capillary movement.

A glass rod was inserted through 5 mm holes punched 5 mm in from each of the bottom corners as a weight to ensure the strips hung vertically. The test strip was hung from a retort stand and clamp, and lowered into a bowl of distilled water so the bottom edge was submersed by about 15 mm. A stopwatch was started and the height of the wetting front from the surface of the liquid recorded at 10, 30, 60 and 300 seconds.

Results

Some of the new mattings when very dry appeared to be partially hydrophobic and resisted easy capillary uptake of water. All matting samples were therefore wetted up first and allowed to air dry overnight so they were no longer damp to the touch, but were not 'bone dry'.

For many of the mattings, capillary rise still appeared to be very slow, and it was difficult, particularly with the black materials, to clearly make out the wet / dry boundary. The following table of results, however, was obtained for the mattings available at the start of the project.

Table 5 Vertical capillary rise (cm) after 300 secs as recorded at Efford - Nov 2000

	Matting type						
Replicate	**2H**	**4H**	**HB**	**SF**	**PPR**	**Flori 1**	**Flori 2**
1	1.2	2.1	3.9	4.0	5.1	8.0	2.1
2	1.1	1.9	3.7	3.4	6.9	6.5	2.1
3	1.7	1.6	2.7	4.8	6.5	6.8	2.2
4	1.9	1.8	2.9	3.6	6.5	7.2	2.0
5	2.0	1.7	2.5	3.1	6.5	7.2	1.9
Mean	**1.58**	**1.82**	**3.14**	**3.78**	**6.30**	**7.14**	**2.06**
SE	0.183	0.086	0.279	0.294	0.310	0.252	0.051

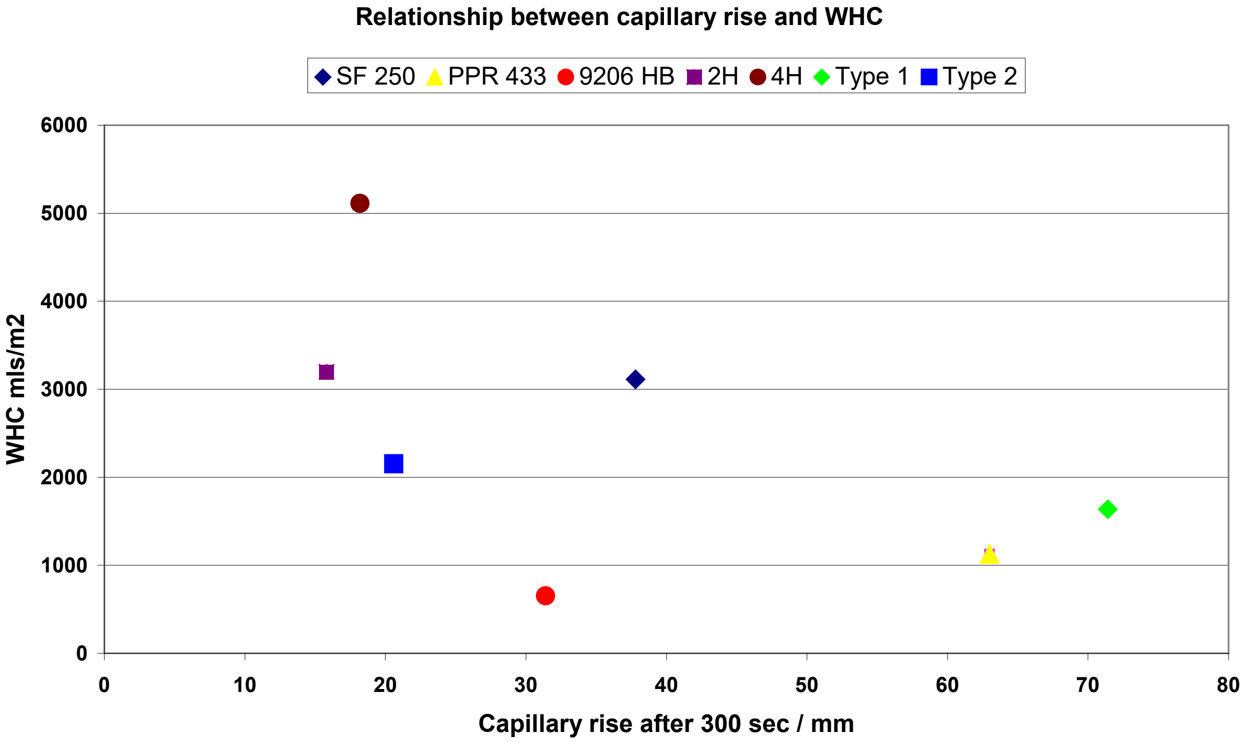
Table 6 Summary comparison of data from matting manufacturers and Efford

Matting type	WHC litres/m² Manufacturer	Efford*	Vertical lift/cm Manufacturer	Efford
2H 5848	3.5	3.14	n/a	1.58
4H 5850	7.0	5.55	2.0	1.82
HB 9206	n/a	0.66	7.0	3.14
Geobond 300g	0.36**	1.34	n/a	n/a
Bato All-In mat	n/a	2.78	n/a	n/a
Florimat 1	1.3	1.57	13.4	7.14
Florimat 2	4.7	2.17	10.5	2.06
SF 250	1.7	2.98	7.0	3.78
PPR 433	0.8	1.13	8.0	6.30
Hydroswitch	n/a	3.25	5.0	n/a
Fybamat	4.0	n/a	4.0	n/a

* Mean of values tested Nov 2000 & July 2001

** Stated to BS 3449:1990, not DIN standard

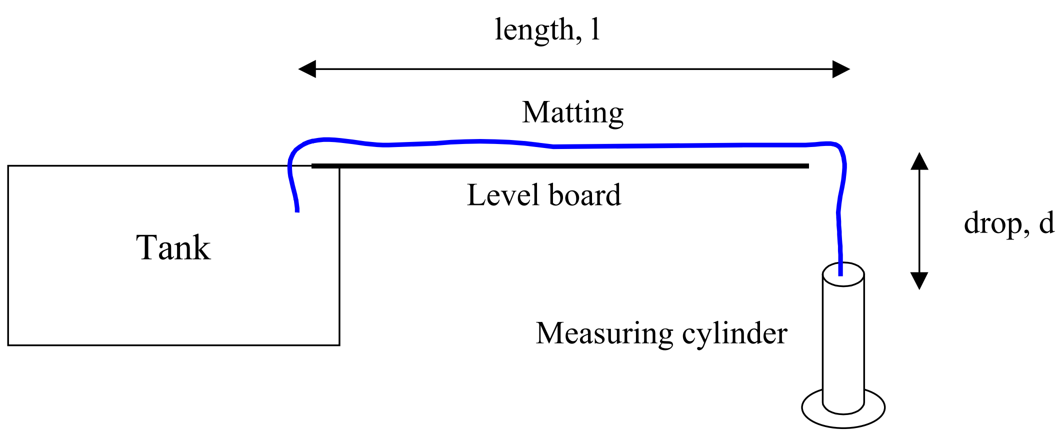
Figure 1 Relationship between mean values for capillary rise and WHC for 7 mattings



Hydraulic conductivity

An attempt was made to develop a technique to assess the 'hydraulic conductivity' of mattings, i.e. a measure of the resistance to flow of water through a mat. This could be important, because good capillary action might not be matched, or indeed might be inconsistent with, a fast rate of movement of water from its source (e.g. a trickle line). Rapid distribution of water from a trickle line would appear to be dependent partly on capillary action and hydraulic conductivity of the mat. A rig was set up as in Fig. 2 below to test the conductivity. The water level in the tank was maintained to the level of a horizontal board, which supported a strip of matting. The far end of the strip was lower than the water level, and so water siphoned through the matting at a rate that depended partly on the length of the board, l, and the drop, d, as well as the characteristics of the matting itself.

Figure 2. Rig to test hydraulic conductivity of matting



Combinations of board lengths of 20, 30 and 50 cm, with drops of 10, 20, 30 and 40 cm, were tried, and flow rates measured. Flow rates were found to be very sensitive to both board length and drop, with short board lengths and long drops giving the greatest flow rate. Flow rate was also sensitive to variations in width of matting strips. Because of the practical difficulties of achieving repeatable results with this system, it was not pursued further.

Discussion

There were several significant discrepancies between the values for both WHC and capillary rise quoted in suppliers' literature, and our test results (Table 6). For example, our results gave noticeably lower values than the supplier's for WHC for 4H and Florimat 2 mattings, but higher for SF 250, PPR 433 and Florimat 1.

Usually, our results for capillary rise were significantly lower than the supplier's data, sometimes by less than half (e.g. for HB, Florimat 2 and SF 250). However, our values for the mattings with the greatest capillary rise of 7.1 cm and 6.3 cm for Florimat 1 and PPR 433 were also the highest amongst the manufacturer's stated values (13.4 cm and 8.0 cm respectively).

There was good consistency between replicates for our results, but particularly in view of the difficulties in accurately determining capillary rise for the darker mattings, it is difficult to know whether our methodology was underestimating values. We also tried using an electrical resistance meter to determine the position of the wetting interface, but this proved unsuccessful.

While the reliability of the absolute values obtained for WHC and capillary rise may be in doubt, the relationship between the two properties shown in Figure 1 illustrates a general trend. I.e. that materials capable of achieving highest capillary lift (typically denser and with a finer network of capillary pathways) have less capacity for storing large volumes of water than more open fabrics which in turn achieve a lower capillary lift. This is an important relationship, because both a high water holding capacity, and reasonably high capillary lift, would appear to be desirable properties of a capillary mat, but are, to some extent, mutually exclusive. The horticultural implication of these physical properties of mattings, however, complicates interpretation, and will need to be considered further in the project. For example, pot, growing media and plant factors need to be taken into account to get a full picture. The relationship between water holding capacity, capillary lift, and the proportion of air to water in the growing media during irrigation cycles, will have implications for healthy plant growth, and matting must not remain permanently wet while still delivering sufficient water to rewet growing media between irrigation cycles.

Despite their limitations, these standard tests will be investigated further in the project, because they offer relatively simple and rapid comparative tests to establish some important physical properties of capillary mattings.

PART 2 - MOVEMENT OF WATER BETWEEN MATTING AND CONTAINERS

The experiments in Part 1 tested the basic physical properties of the matting materials. The objective of the next stage was to test how well capillary matting would move water up a slight incline and into containers of growing media. The aim was to develop a standard method that would test both the ability to distribute water laterally through the mat, but also deliver it from the matting up into a pot. This would take into account the interface between the base of the pot and the matting, where clearly capillary contact must be maintained to move water into the medium.

Theory behind the method

The hypothesis was that a constant supply of water to the mat at the base of the slope would maintain capillary contact through the matting with pots lined up the slope to a certain level. Starting with fully wetted pots in good contact with the matting, containers higher up the slope, where there was greater capillary tension, would be expected to dry out faster than those at the base of the slope, where the moisture status of the matting was greatest. In theory, a dynamic equilibrium would be reached eventually where the water status in the container was a function of its position up the slope, and the capillary matting's ability replace water lost from the top of the pot by evaporation. Assuming the height above the water supply at the top of the slope was excessive, there would be a point somewhere up the slope where capillary contact between the matting and the base of the container would fail. Pots at this point and above would continue to dry out with no replenishment from the matting. For a given pot and growing medium, it was hoped that different mattings could be characterised by:

1. How far up the slope capillary contact could be maintained.
2. The water content of containers at different levels up the slope. Different mats might have different shaped graphs of water content vs. position up the slope.

Method

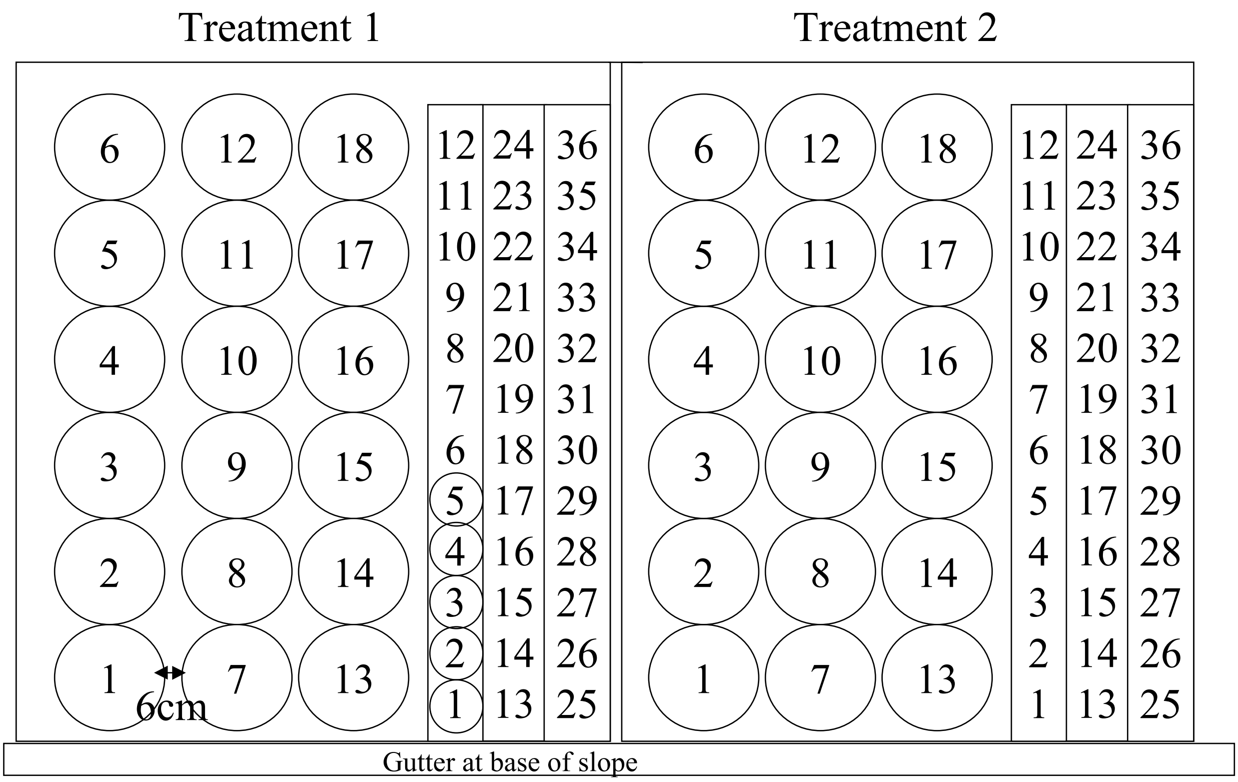
Test beds were constructed in order to assess how well capillary mats could pull water up a gradient and into a container. Four test beds were built using 2.4 m x 1.2 m sheets of board supported on a tubular steel framework. Sufficient reinforcement of the boards underneath with timber struts and wire cable 'bow bracing' was necessary to avoid the boards sagging under the weight of containers. The bench tops were sealed with heavy-duty white-on-black polythene. The framework incorporated nut and bolt adjusters along one of the 2.4 m edges so that the board could be levelled or a slope set as required. A gutter was fixed along the lower edge and inclined inwards slightly. A tank and pump was used with a height adjustable return outlet set in the gutter, so that a constant level of water could be maintained along the bottom edge of the board. The beds were located in a glasshouse compartment.

3.0 litre (Optipot 19T) and 9 cm (Plantpak 9F) containers were selected because they had smooth and flat bases that would make good contact with the matting. These two sizes were also representative of containers relevant to nursery stock crops. Both sizes of containers had 6 holes in the base. The 3.0 litre pots also had 6 additional drainage ports around the base of the sidewalls.

Pots were filled with 100% Scotts Premium Nursery Stock Peat (medium / coarse grade). No wetting agent was incorporated. A standard filling, tapping and levelling procedure was adopted to try to ensure reasonable uniformity between containers. After watering in and settling, some further topping up of pots was carried out. For most of the experiments, the four beds were split into two matting treatments with an approximate 1.2 m square of capillary matting on each half, but separated by a narrow gap to avoid interference.

Three replicates rows of each of six 3.0 litre and twelve 9 cm pots were set out down the bench for each treatment (Figure 3).

Figure 3. Layout of pots on test benches. One of four beds in total.



It was decided that containers of growing medium without plants should be used at this stage of the project to try to avoid introducing variations in water loss from pot to pot according to plant size and stage of growth. In addition, plant deaths and growth differences were likely to occur with containers that dried out completely, causing further complications.

It was important to ensure that the growing media in the containers was uniformly wet at the start of each experiment. Beds were therefore set level initially, the water level in the gutter adjusted, and the mattings checked for even wetting over the whole bed area. The containers, following careful overhead watering, were placed on the bed, and weighed over several days until their weights had stabilised. As the mattings were more or less at full capacity at this stage, containers absorbed more water and typically became slightly heavier than they would be at 'pot capacity' (i.e. after soaking and free drainage).

Once a set of stable starting weights for each container was established, the test benches were inclined. Initially, slopes of 2%, 4%, 6% and 10% were examined. It was found that a 10% incline gave sufficient height to ensure that the top edges of the mats drained down a point where they eventually failed to maintain a good capillary link with the water source. This slope, which over a distance of 1.2 m down the slope, equated to a maximum elevation of 12 cm between the bottom and top of the slope. This 10% slope was used as a standard in all the experiments.

All containers were weighed at intervals of about 2 - 7 days over a period of time to allow an equilibrium to develop and containers to more or less reach a stable weight (Appx, Photos 1-2).

A series of experiments were run between September 2000 and late February 2001 using different mattings, and examining the effect of covering materials on those mats that did not incorporate their own geotextile or surface layer.

Results

The following experiments were undertaken.

Experiment 1: Initial tests 23/10/00 - 6/11/00
This established the procedure and the degree of slope to use (data not shown).

Experiment 2: 23/10/00 - 7/12/00
Comparison of 2H and 4H and HB mattings

Experiment 3: 6/11/00 - 7/12/00
Comparison of PPR 433, SF 250, Florimat 1 and Florimat 2 mattings

Experiment 4: 11/12/00 - 8/1/01
Repeat of Experiments 2 & 3, but using a layer of Mypex groundcover over the mattings. Nb. Mypex with the red stripes was used as this was understood to have a slightly more permeable weave.

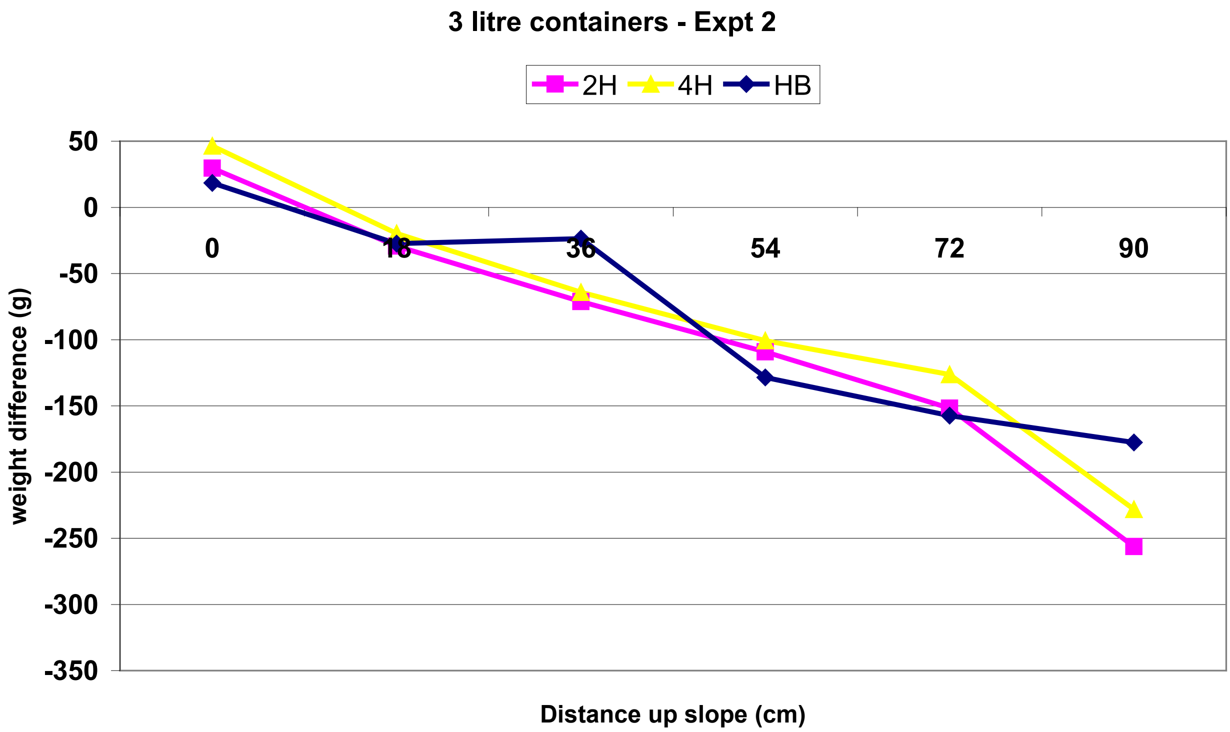
Experiment 5: 11/1/01 - 15/2/01
Comparison of three mattings incorporating an integral geotextile or perforated polythene layer, plus a test with Fyba mat with and without a Mypex covering.

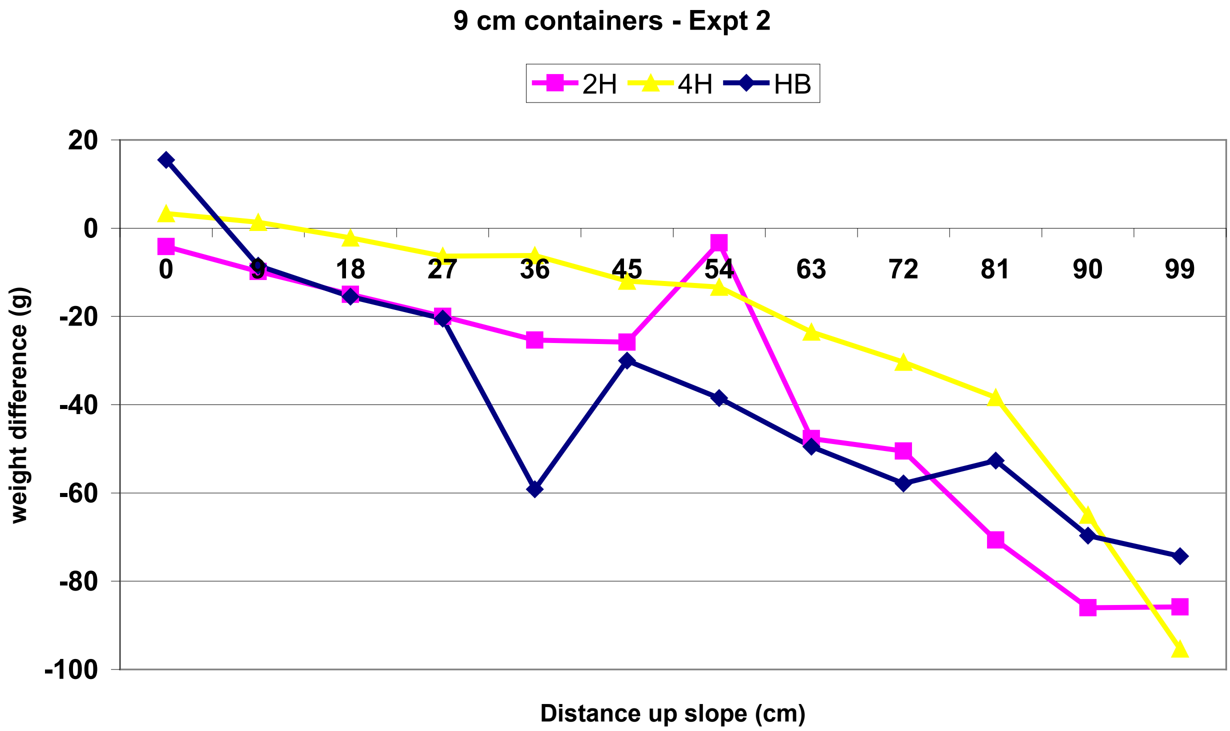
Experiment 6: 17/1/01 - 28/2/01
Using just Florimat 2 matting, uncovered matting was directly compared with using Mypex or Tex-R (a Spin-Out treated geotextile) as a covering layer.

The 3.0 litre containers weighed approximately 1900 - 2000 g when fully wet at the start of each experiment, and the 9 cm pots were approximately 270 - 300 g.

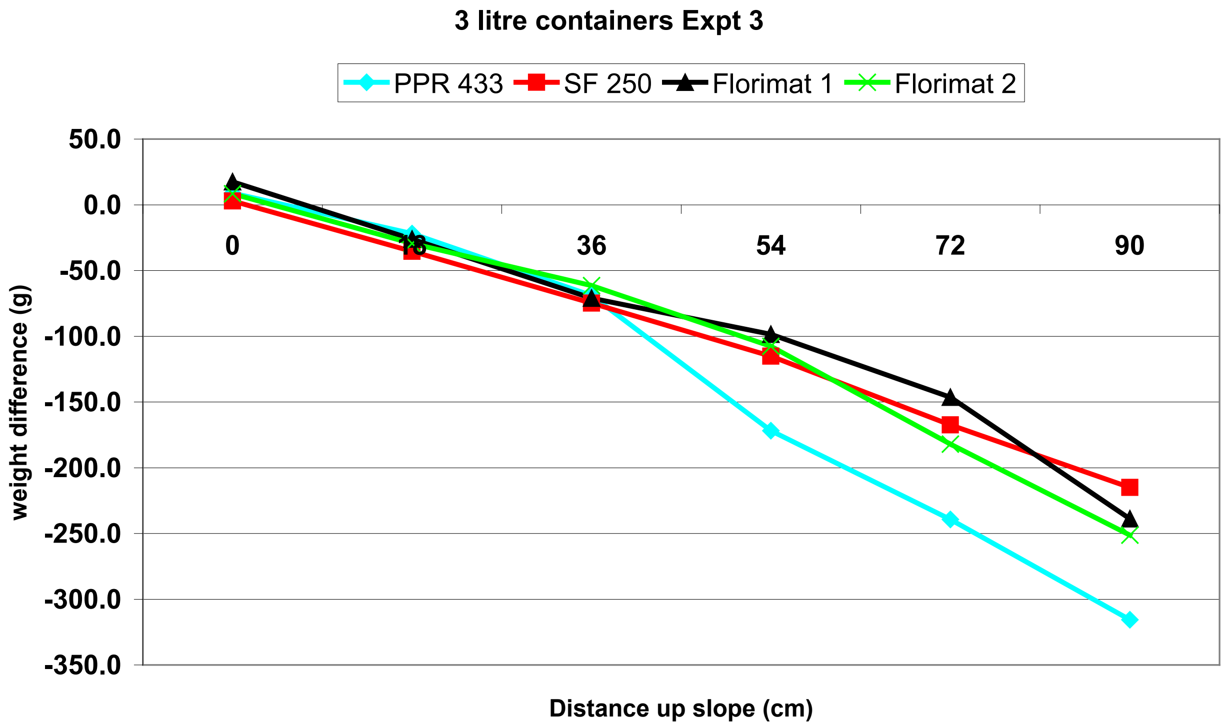
To take account of minor variations in volumes of media and therefore starting weights between containers, weight differences from the initial starting weights were calculated for each container and used to express the results.

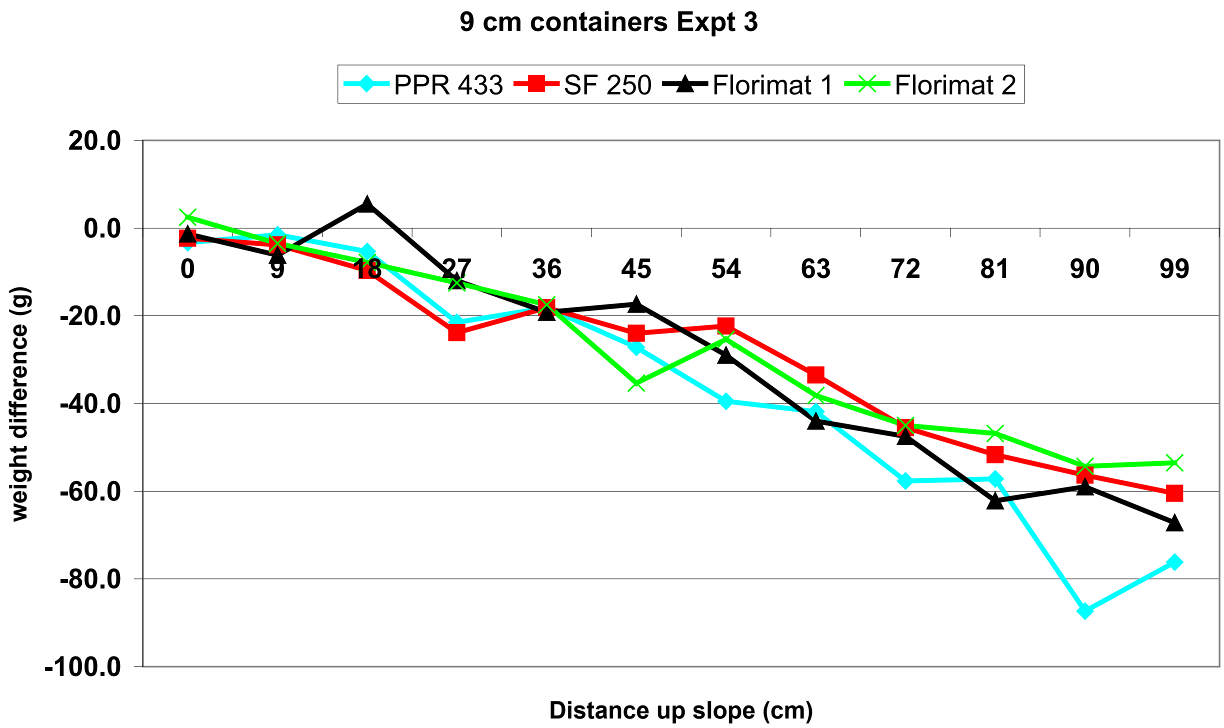
The charts below summarise the weight differences between the starting weights and final weights of containers at intervals up the slope. Each data point is the mean of three replicate containers.





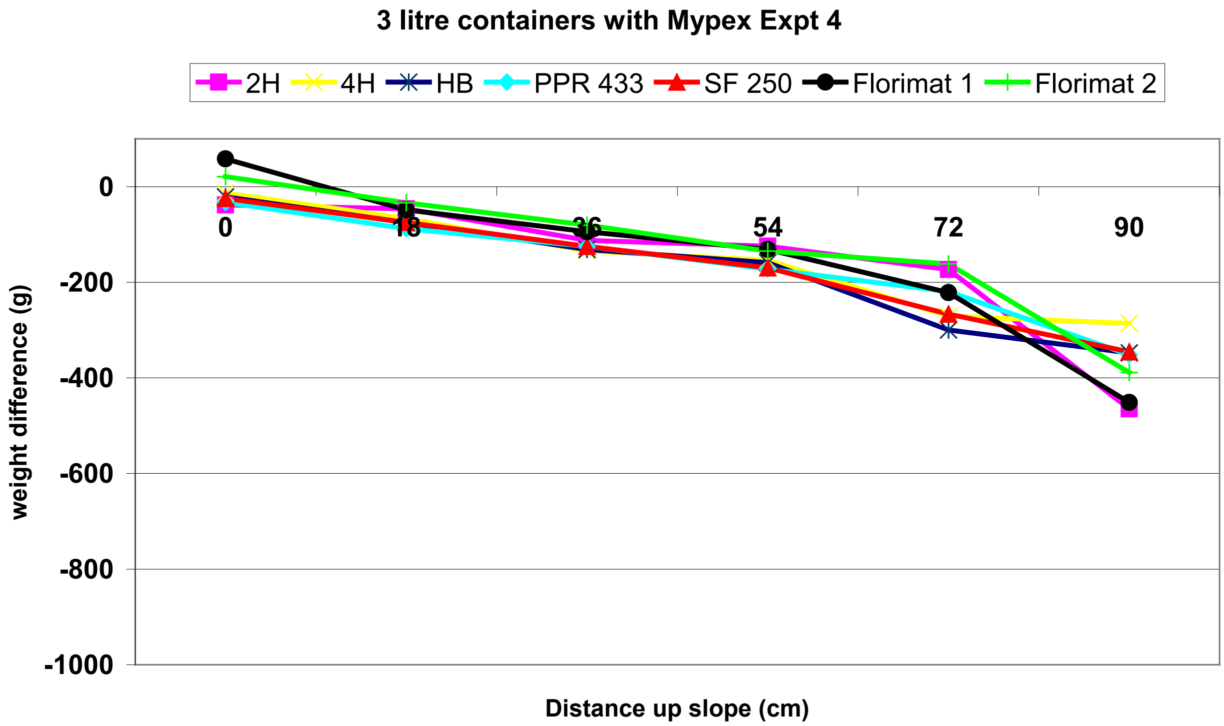
With the 3 litre pots, the three mattings showed broadly similar weight losses, reaching a maximum of about 200 - 250 g at the top of the slope. However, this represented only about 10% of the starting weight. The 9 cm pots lost a greater proportion of their starting weight with up to a 30% loss in this experiment. The thicker 4H mat with a higher water holding capacity appeared to be maintaining pots slightly wetter up to 80 cm up the slope where water loss showed a marked increase.

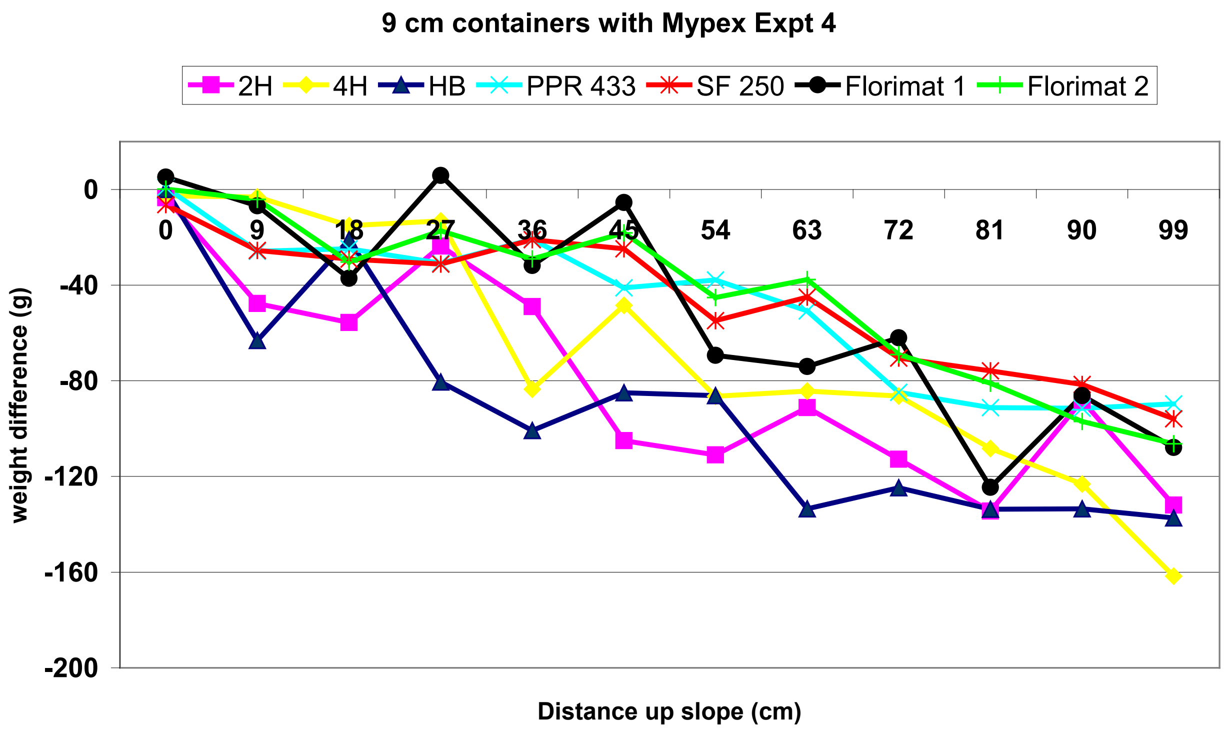




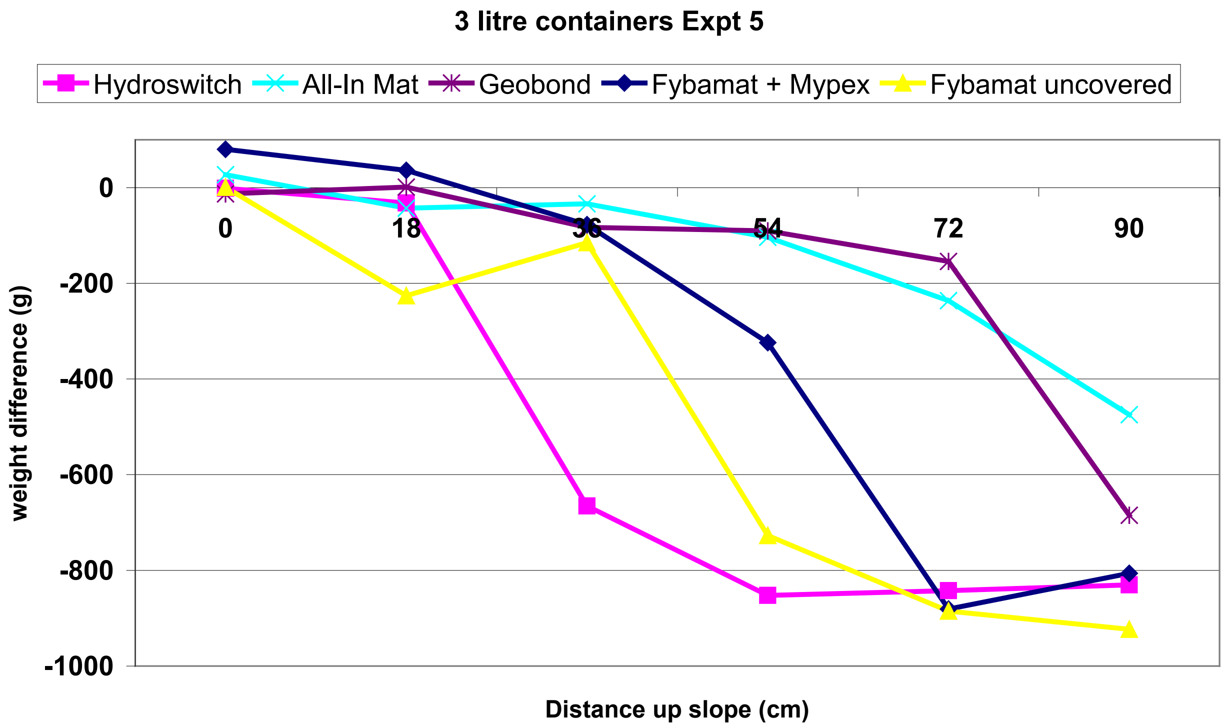
Although Experiment 3 started a few days later than Expt. 2, they then both ran concurrently until 7 December, and so results can be compared. As with Expt. 2, the 3 litre containers showed a smooth and gradual weight loss across the slope by the end with little difference between the matting types. The pattern was similar with the 9 cm containers, but the SF 250, and both Florimats had only lost about 60 g at the top of the slope compared to about 80 - 100 g for the 2H, 4H and HB range. PPR 433 appeared to show a slightly greater water loss.

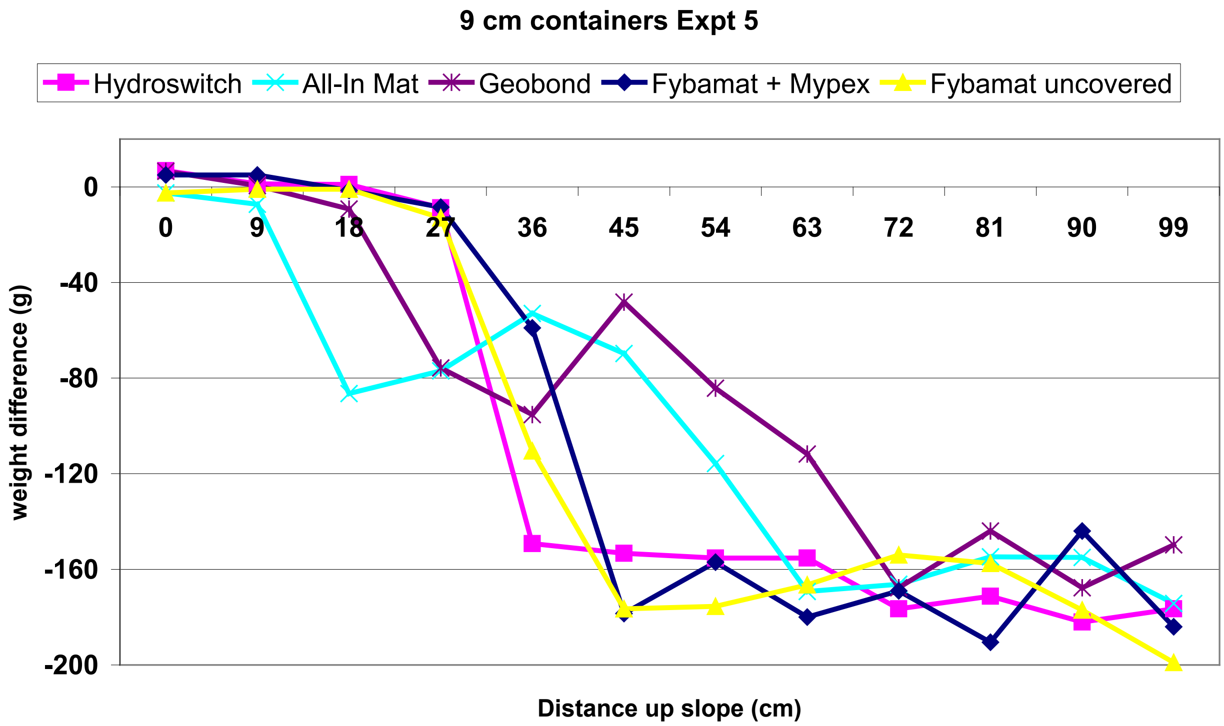
In general, although the expected pattern of water loss up the slope occurred in this experiment, containers were very slow to dry at this time of the year.



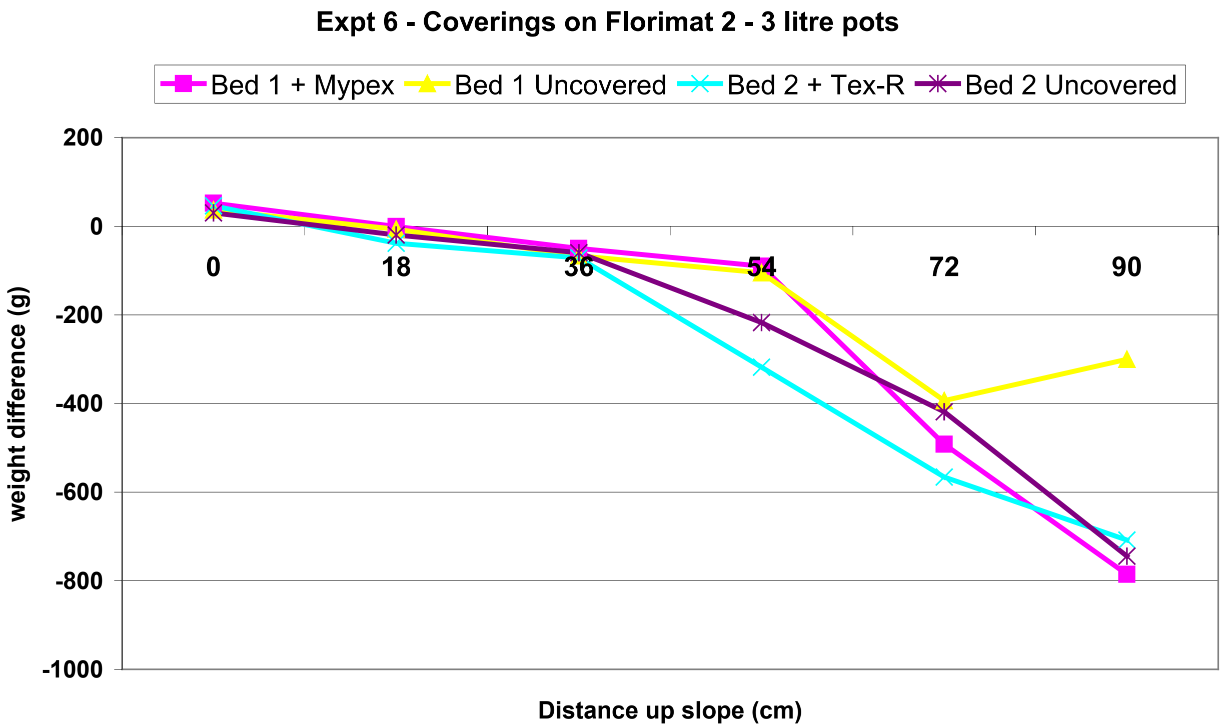


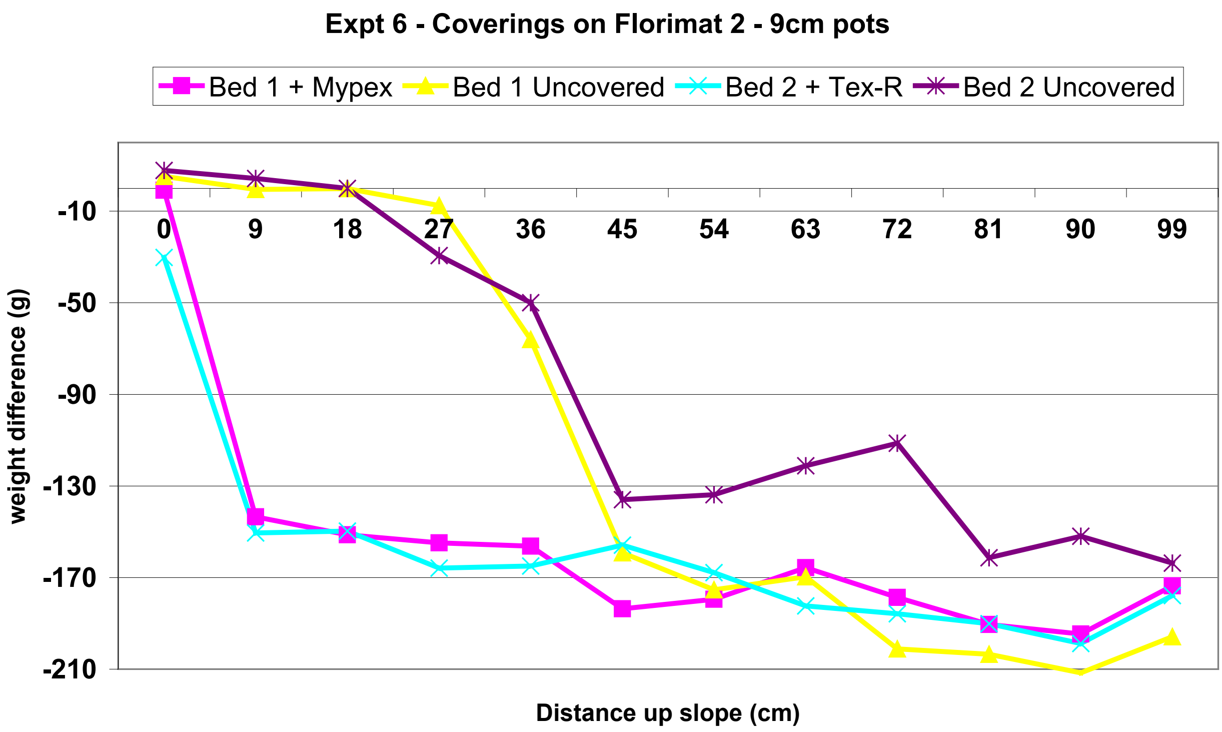
The addition of a layer of Mypex to the capillary mattings did not appear to greatly affect the rate of water loss where 3 litre pots were used. In Expt. 4, the final water loss values after 4 weeks were broadly similar to the previous experiments for the 3 litre pots, although this reached 500 g or 25% of the starting weight for a few mattings at the top of the slope. With the 9 cm pots, however, the Mypex layer appeared to cause variable weight loss across the slope for most of the mattings. Final water losses were also proportionately greater for some mattings, reaching 160 g or about 50% of the starting value at the top of the slope for 2H, 4H and HB.





The first experiments with the mattings incorporating an integral ground cover or geotextile layer took place over a 5-week period from 11 January 2001. At this time, temperatures and light levels were rising, and drying out of the containers proceeded more rapidly and completely by the end of the experiment. The All-In mat and Geobond held water levels for the 3 litre pots up to the 72 cm position up the slope, but the Hydroswitch mat and both Fybamat treatments showed rapid drying after the second or third pot up the slope. With the 9 cm containers, drying out was very rapid beyond the fourth pot at 27 cm although the All-In mat and Geobond continued to supply water for further up the slope.





It was only possible to examine a the effect of coverings on a single capillary material, and Florimat 2 was chosen as there was a ready supply, and it was a well established brand. The influence of Mypex and Tex-R on maintaining capillary contact showed a marked difference in response between the two container sizes in Expt. 6 (Appx, Photos 3-4). Here, capillary contact with the 3 litre pots appeared to be well maintained across all treatments to between the 36 and 54 cm level after which pots dried rapidly. With the 9 cm pots on matting covered with both Mypex and Tex-R, however, capillary contact was lost with the second pot up the slope.

Discussion

The objective was to develop a standard test that would both characterise the ability of a mat to distribute water laterally and up a slight slope, but also deliver it from the matting into a pot. This technique appeared to be successful provided containers were left to dry down sufficiently for equilibrium to be reached. However, this proved very slow over the winter months, and may not therefore have allowed treatment differences to fully develop in the earlier experiments. The technique was tedious to carry out with 432 pots having to be individually weighed on each occasion when all four test benches were being fully utilised! If the method is to be used as a standard test, it would be important to ensure drying conditions were sufficient to achieve a final weight value quickly. Under these conditions, once a stable starting weight of pots had been established, it might be sufficient to just weigh containers twice after a few days to check they had developed their equilibrium position on the slope.

The influence of a geotextile layer such as Mypex or Tex-R had a striking effect on the ability of the non-covered mattings to maintain capillary contact in this situation. The relative difference in response between the two container sizes was almost certainly due to their different weights. The lighter 9 cm pots would have pressed less firmly on the geotextile and matting making it easier for the crucial capillary contact with the growing medium to break down. This clearly has important implications for the performance of capillary mats. Products such as Geobond and All-In matting have been designed so that the capillary matting fibres are pulled through the geotextile layer in an attempt to improve capillary contact. The results from Experiment 5 suggested that they were achieving this compared to other mattings with Mypex laid on top.

The mattings which in the Stage 1 tests had shown the highest vertical capillary lift, i.e. PPR 433 and Florimat 1, did not show any marked ability to maintain better capillary contact with containers higher up the slope than many mattings such as 2H and 4H with a lower rating. In this respect, therefore, these tests did not single out any particular matting as being favourable to take on to the next stage in the development of the capillary flow bed.

The tests described above were of value in assessing the ability for mattings to redistribute water to pots against a slope, and to test effects of geotextiles, for example, on capillarity at the interface between the mat and the growing medium in the pot. Under spring, summer and autumn conditions under glass, drying out of pots to the ‘equilibrium point’ should be sufficiently rapid for this to be a practical standard test.

To take the tests further and closer to their use in horticultural practice, the next stage was to use the mattings in a dynamic irrigation process. I.e. mats are wetted up, allowed to dry down and rewetted again. In horticultural use, the aim is clearly to match the supply of water to the demands of the growing crop without subjecting the growing medium to excessively long periods of saturation at the base of the pot, nor allowing the mat / growing medium to dry to the stage where capillary contact is broken and cannot easily be recovered.

The next step in the project was, therefore, to examine the ‘capillary flow bed’ technique, to further assess mattings in a dynamic, but controlled environment, with a growing crop. As in other capillary irrigation systems, here matting is irrigated via trickle or drip lines at a spacing across a width of matting that will ensure even distribution of water between irrigation cycles. However, unlike glasshouse bench systems, which are typically level, a very gentle slope is used to both help even distribution of water, and remove surplus water if required.

PART 3 - DEVELOPMENT OF THE CAPILLARY FLOW BED

The ultimate objective of this stage of the project, is to develop the capillary flow bed as a practical irrigation and growing system for HNS under protection, determine which matting types are suited to it, and how they are best managed. It is possible that several types of matting may 'do the job', but they will require managing differently to be most effective. As hinted at from the experience so far using matting coverings with 9 cm and 3 litre containers, it may be that some mats work best for large and heavy containers.

The principle of the capillary flow bed technique was first described by Dr Volker Behrens, Geisenheim Institute, Germany (*Horticulture Week* 23/5/1996, 25-29). Water is supplied via trickle or drip line to the upper edge of matting on a gently sloped bed. Gravity helps ensure even distribution of the water across the mat down the slope, while capillary pull up the slope ensures some water is retained by the mat. In its original form, published by Behrens, surplus water runs off the mat into a gutter and is recirculated. However, it should be possible to supply just sufficient water to wet the matting without it becoming saturated and draining.

Behrens describes several layouts, where a 1% - 2% slope is used down the length of the bed. However, the variation that is being examined in this project is to use a slope <u>across</u> the bed. Providing the width of the bed is not excessive, it should be possible to supply sufficient water from either a single irrigation line running down the raised side of the bed, or with an additional line (e.g. down the centre). Recommendations for spacing of irrigation dripper lines vary from about 45 to 110 cm according to whether water is hard or soft, and whether matting is used on a sloping or level base (Richardson, 1999). These recommendations for the maximum fall across a slope for a single piece of matting state that it should not exceed about 2/3 of its vertical capillary lift. Thus, if matting achieves a capillary lift of 10.6 cm, the maximum fall across a strip of matting should be no greater than 7 cm. For a 2% sloped bed, this would give a maximum width of 3.5 m. Factors including slope and irrigation line spacing are being examined in this part of the project.

Method

The principle of using boards to construct a bed incorporating an adjustable incline had worked successfully for experiments described in Part 2. By supporting this on a frame at a convenient working height, containers could be also be handled and recorded conveniently. This method was adapted, therefore, to construct a prototype capillary flow test bed. The board was inclined at a slope of 2% (i.e. a fall of 4.8 cm) down the 2.4 m long direction, to represent a cross section of a commercial bed with a realistic width.

An irrigation drip line (T-tape type 506-20-250) was used across the top of the bed and another about half way down the slope. Emitters were spaced at 20 cm and the stated flow rate was 250 litres / hour / 100 m at 0.55 bar (8 psi) pressure. This gave a total of 12 emitters on the test bed with a theoretical water delivery of 6 litres / hour for a bed area of 2.88 m^2. Florimat 2 matting was used to cover the bed, but no additional covering such as Mypex was used on top. Only a single matting was used to test the basic principles of the bed in this pilot study, and Florimat 2 was selected as a ready supply was available rather than because it had demonstrated any particular merits in earlier tests.

A crop of pruned Hydrangea plants in 3 litre pots was set out on the bed in mid February 2001 (Appx, Photo 5). They were spaced pot thick initially with 6 pots across the bed by 12 pots down the length of the bed (72 total). The T-tape was set between the first two rows at the top of the slope and between rows 6 and 7 halfway down the slope. An additional short length of T-tape running into a bucket was used to record the amount of irrigation on a daily basis. Irrigation was controlled with a time clock triggered solenoid valve, and adjusted periodically according to the water status of the plants and the weather.

A sample of 18 plants was weighed on a daily basis during weekdays between 15 February and 15 May. Three plants from rows 1, 3, 6, 7, 11 & 12 were weighed giving an indication of water distribution at the top and bottom of the slope as well as the middle and edges of the bed.

A high density of plants was deliberately used at the start of the trial to maximise water use from the bed and give a good test of the capability of the system. However plants were too overcrowded by mid April, and so the density was halved to three plants per row set out on a staggered spacing.

Results

Figure 4

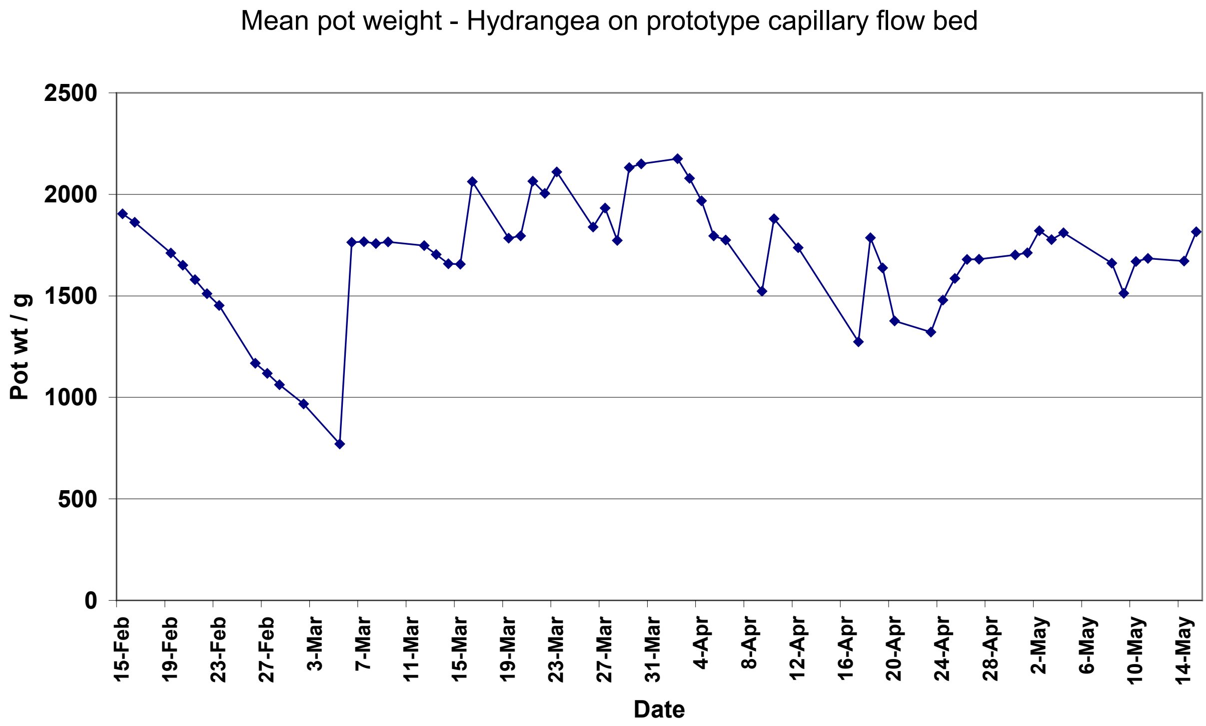


Fig. 4 illustrates the mean pot weight for the bed over the three-month period of assessment. Over the first two weeks of the trial, while the irrigation regime was being adjusted, a net deficit of irrigation was applied to a point in early March where some pots began to wilt. From then on, sufficient irrigation was supplied via the matting to support the crop's needs with virtually no hand watering required. However, manual adjustment of the time clocks was necessary according to the weather, and it proved difficult to do this very precisely resulting in temporary over or under watering requiring further adjustments.

Over the whole period of the experiment, the amount of water applied to the bed averaged 2.3 litres / day (0.8 litres/m^2 of bed). However, this reached peaks during hot sunny weather and full crop cover of about 17 litres/day (5.9 litres/m^2/day). Occasionally, there was a small amount of drainage from the bed, which typically followed occasions when extra irrigation was needed to correct a drying out period. Mostly, however, the bed ran satisfactorily without irrigation to run-off being required.

Water status in containers over the bed was typically reasonably uniform (Fig. 5), but occasionally when time clocks were not adjusted sufficiently to cope with hot spells of weather, drying out of the lower (south) end of the bed, and some pots along the sides could occur (Fig. 6).

Figure 5.

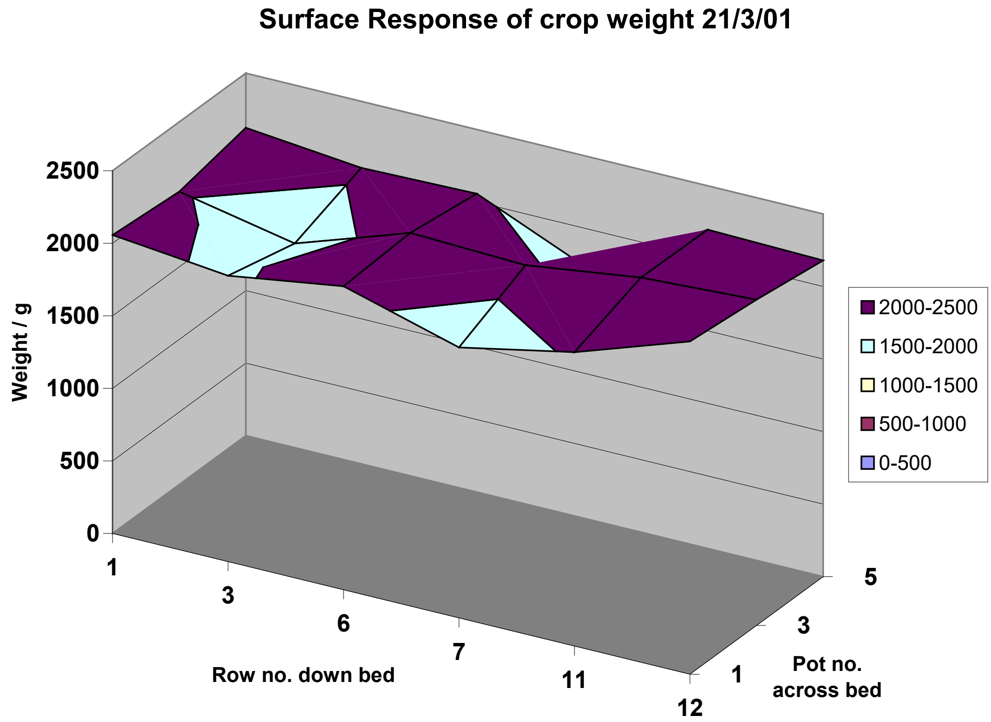
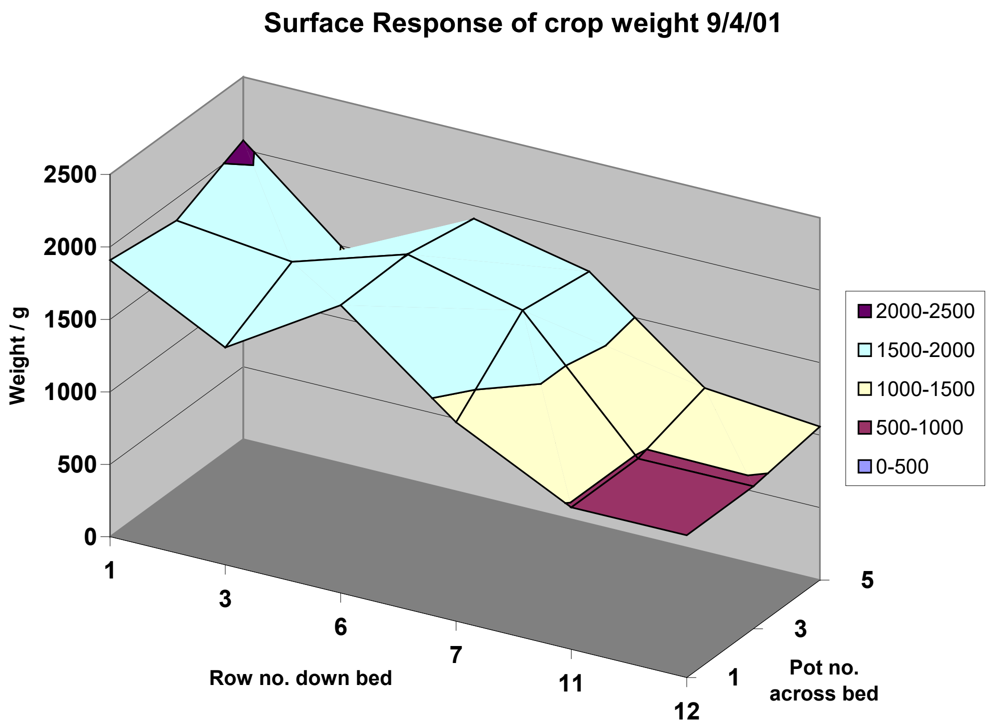


Figure 6.



Discussion and further work

Experience with the prototype capillary flow bed was promising, but it is clear that if critical experimental comparisons between matting types are to be undertaken, a much more precise and automatic control of irrigation will be required. An array of eight experimental capillary flow beds have been constructed in a glasshouse compartment in preparation for the work in Year 2 of the project (Appx, Photo 6). Automatic irrigation control for each bed will be set up using a surface capacitance probe designed to detect the wetness of the matting, and switch the water supply solenoids. It should be possible, by setting 'wet' and 'dry' switching points to run growing media through greater or lesser fluctuations in the wetting and drying cycle, as well as being able to set the mean level of moisture content of the growing medium.

Experience in the use of automated control at this stage will also help towards fulfilling the longer-term objective in the project of developing a semi-commercial scale automatically irrigated growing bed for HNS under protection.

The flexible arrangement of experimental beds will enable the following factors to be examined in Year 2:

- A comparison of total water use and water distribution over the bed for 'covered' and 'uncovered' matting types.
- Determine working tolerances for mattings including:
  a) Sensitivity to different slopes
  b) Tolerance of 'bumps and hollows' (i.e. imperfections in the bed profile)
  c) Spacing of irrigation lines
  d) How far managing irrigation set-points can be used to achieve uniform irrigation with these factors.
- The influence of type of growing media, and use of additives such as wetters, on the performance of capillary bed systems (also drawing on project HNS 107a).

Following experiments using the eight test beds under protection, a larger scale capillary flow bed will be constructed under a polythene tunnel during Year 2. A semi-commercial sized area of crop will be compared with other irrigation systems including overhead sprinklers. Experiments with this larger-scale system will be started in Year 2 and continue in Year 3, although it is expected that the glasshouse irrigation test-beds will also be required for further experiments in parallel.

Finally, costs of mattings (with additional base and geotextile layers if not an integral part) will need to be taken into account when growers are choosing mattings. Materials and running costs will be considered further in Year 2.