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PRACTICAL SECTION FOR GROWERS

BACKGROUND AND OBJECTIVES

Growers are under increasing pressure to improve the efficiency of water use and reduce losses of fertiliser to the environment. These pressures include the high cost of mains water, environmental legislation, customer demands and environmental responsibility.

UK growers are not unique in the pressures that they face. Growers in some European countries (e.g. The Netherlands and Germany) have to deal with very strict legislative controls in place to protect the environment. In these countries growers have to demonstrate that the production systems used do not lead to environmental pollution. Some States in the USA face similar pressures and in many regions of Australia growers are having to reduce water consumption. Lessons can be learned from these countries even though UK growers are not yet facing the same environmental pressures.

This project aimed to enable UK growers to compare different irrigation and growing systems in order to help in the selection of systems that reduce water and fertiliser wastage, help meet customer and accreditation demands and comply with legislation. The project also aimed to provide growers with costings information to compare systems for irrigation and run-off treatment as well as to identify targets for future research and development work.

SUMMARY OF RESULTS

Evaluation of the Efficiency of Water and Fertiliser Use

The research was divided into two stages. The first stage was designed to assess the variation in efficiency between a range of different production systems and the second stage was designed to quantify water use and loss throughout the Poinsettia production season for four selected systems.

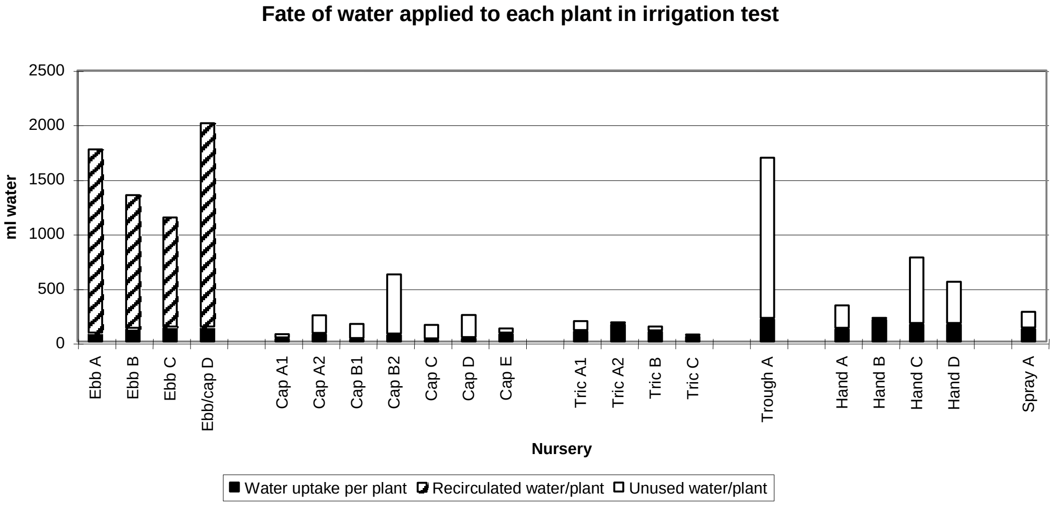
<u>Stage 1</u>
The primary objective of Stage 1 was to establish the degree of variation of water loss between and within different growing systems. Seven production systems were identified as being the most widely used for the production of protected ornamentals. These were as follows:

- ‘Ebb and flow’ flood benching
- Overhead gantry (application usually to capillary matting)
- Hand-watering (using hosepipe)
- Capillary (various systems using capillary principles)
- Drip / trickle
- Overhead spraylines
- Trough track

Nurseries using these systems, for the production of Poinsettia were identified and an 'irrigation test' was carried out during week 38 of 1999. The irrigation test consisted of calculating the quantity of water applied to a measured batch of plants and then calculating the quantities of water actually taken up by the crop and the quantities unused. In nurseries that were not recirculating water the quantities unused were assumed to be lost to the environment.

AFP (air filled porosity) and particle size tests were carried out on the different growing media used and water samples (untreated, irrigation and run-off water) were analysed at each nursery for nutrient content.

The chart below shows an estimation of what happens to the water applied to each Poinsettia pot in the nurseries tested in one irrigation cycle.



Key to abbreviations used on the graph:

- Ebb = Ebb and flow benches (recirculating systems)
- Cap = Capillary matting systems with varying water application methods
- Tric = Trickle irrigation (dripper to each pot)
- Trough = Trough track
- Hand = Hosepipe watering
- Spray = Overhead spraylines

Fertiliser losses and costs for the whole growing season can be extrapolated from the data collected in Stage 2. For example, nursery Cap B2 looses over £450 worth of fertiliser (450 Kg) for every 10,000 plants grown. This compares to nursery Cap A1 loosing £60 (60 Kg) and nursery Tric A2 loosing less than £10 (10 Kg) worth of fertiliser, through the season, for every 10,000 Poinsettia plants grown.

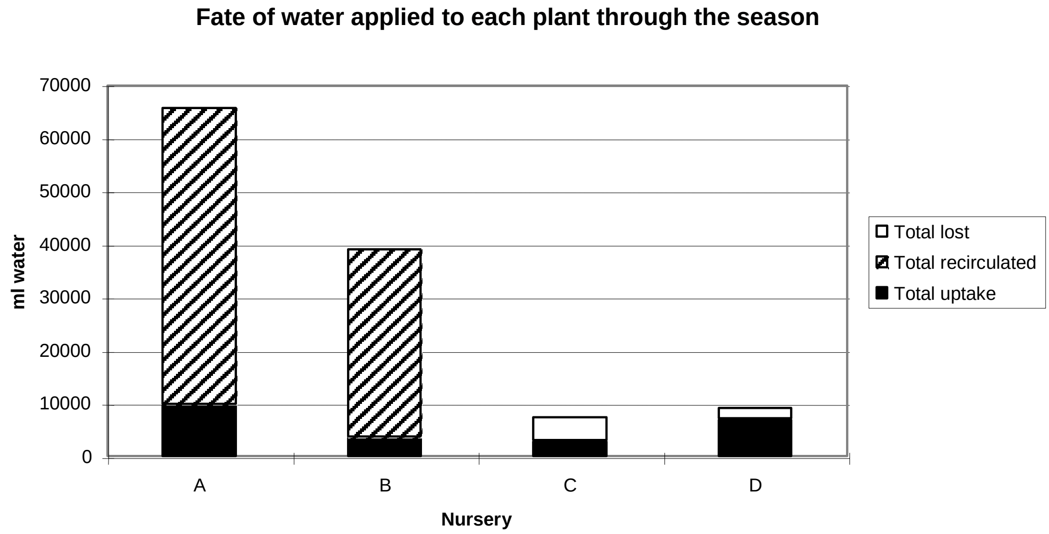
<u>Stage 2</u>

This stage further developed the work in Stage 1 by identifying four nurseries and measuring water and fertiliser usage throughout the whole Poinsettia growing season. The four systems tested were as follows:

A	Ebb and flow flood benches 10m^2 (recirculating). Flood for 12-15 minutes per irrigation.

B	Flooded capillary matting on benches (recirculating). Water is released onto one end of the bench and allowed to flood the bench. Capillary matting on the bench helps to retain some water after the flooded water has drained away.
C	Plants standing on open mesh benches overlaid with capillary matting ('fleece'). Irrigation is applied by an overhead gantry with nozzles directed beneath the foliage to the matting.
D	Plants spaced on heated benches overlaid with polystyrene overlaid with polythene overlaid with capillary matting overlaid with perforated polythene. Irrigation is applied by a hosepipe with lance.

The chart below shows what happened to the water applied to each plant in the four systems tested in Stage 2.



This chart clearly shows large variations in the quantities of water applied by nurseries A-D to a standard crop. However, real water losses only occurred in systems C and D as systems A and B were recirculating. The cost of the water and feed applied in each system can be calculated based on a standard proprietary feed cost of £1/Kg and a water cost of £0.67/m^3. The costs for producing 10,000 plants are shown below:

	£/10,000 plants					
Nursery	**Cost of water applied**	**Cost of feed applied**	**Total cost of applied water and feed**	**Cost of water lost**	**Cost of feed lost**	**Total cost of unused/lost water and feed**
A	66*	44*	110*	0**	0**	0**
B	25*	46*	71*	0**	0**	0**
C	51	50	101	31	23	54
D	63	100	163	15	57	72

* Uptake only as the rest was recirculated
** All water and feed was used as the system was recirculated

Nursery B is the lowest cost system to run, in terms of water and feed costs. Although water and feed was not lost from the system in Nursery A, the input costs were relatively high due to larger quantities of water used by the crop.

Guideline costings were produced for ten different systems on an example one acre nursery. A summary of these results is shown below:

System	Set up cost per m^2 (£)	Annual running cost (£/m^2)
Ebb & Flow Floor (Recirculated)	28.60	0.51
Ebb & Flow Floor (To waste)	27.80	1.12
Ebb & Flow Benches (Recirculated)	33.29	0.48
Ebb & Flow Benches (To waste)	32.39	1.00
Gantry	23.18	0.67
Overhead	1.71	1.01
Hand-watering	0.46	1.38
Capillary Matting	2.24	1.02
Drip	2.92	0.39
Trough Track	26.63	0.83

It is recommended that growers read the full report, showing the assumptions made, before using these figures in project planning.

Options for improving efficiency of water and fertiliser use

For many growers a complete change to recirculating systems will be impractical. For this reason this project has assessed each of the currently used systems to see how they can be modified or what practices can be applied to make them more efficient.

Ebb and flow and trough track systems should be designed with built-in recirculation. Water tanks (containing liquid feed) should be allowed to run down to low levels before emptying out. These are high investment systems but have many additional benefits, including increased throughput and improved crop handling. They are commonly used in The Netherlands, Germany and Denmark and have a place for quality crop production.

Capillary systems should apply water 'little and often' and ensure the use of high quality level matting. This research highlighted the different ways that different people treat capillary systems. Nursery Cap B2 had the same system as nursery Cap A1. The only difference was that Cap A1 turned the water supply on for 9 minutes and Cap B2 turned the water supply on for over an hour. Nursery Cap B2 could easily change practice to dramatically improve efficiency with no cost to crop quality.

Drip systems offer good water saving potential for pot production as long as drippers are regularly checked. Nursery Tric A2 only lost 11% of the water applied compared to the capillary systems, most of which lost over 80%. Drip irrigation works well for pots 1 litre or greater in size. They would be impractical to install onto smaller pots and packs.

Hand-watering systems can be efficient if supplemented with capillary matting and careful application by trained staff. Nursery Hand B (nursery D in Stage 2) is an example of an efficient hand-watering system where careful application to capillary matting over polythene on benches only lost 8% of the water applied. In contrast nursery Hand C lost 78% of the applied water. There is a high labour cost associated with this method of irrigation and as labour supply becomes harder to find growers should seek alternative irrigation methods

Spraylines are difficult to improve and inherently inefficient. Careful choice of nozzles can help to reduce the loss of water onto paths. These systems should be used as little as possible and alternatives should be sort when installing new systems.

Gantry systems provide well targeted water application. Shutting off nozzles irrigating hard surfaces can reduce wastage.

Avoiding Pollution

In most cases (except for the recirculating systems) the water that was not used by the crop was lost as run-off from the glasshouse. In the case of most systems the water seeped into the ground beneath the structure or drained out of the end of the glasshouse. Where these glasshouses are located near to watercourses or sensitive groundwaters then there is the possibility of water pollution for which a fine could be charged if discovered by the Environment Agency.

Legislation in the UK

Fertilisers are rarely applied directly to soils in protected ornamental production but there can still be considerable run-off of nutrients to the ground. The area under protection can become a **point source** of pollution, possibly exceeding agricultural levels. Therefore, the following aspects of legislation should be considered:

- Water Resources Act 1991 - follow the new horticulture sections in the MAFF ‘Water Code’.
- Groundwater Regulations 1998 - Ensure that these regulations are complied with and listed pesticides and fertilisers are only disposed of onto authorised sites.
- FEPA - Prevent water contamination by pesticides by following the regulations.
- Drinking Water Directive - Ensure run-off is not causing nitrate levels in adjoining watercourses to exceed the limit of 50 mg/l nitrate.
- Water Abstraction Licensing - Obtain a copy of ‘Taking Water Responsibly’ (from DETR) and plan future abstractions and water uses in the light of these proposals.
- Nitrate Vulnerable Zones (NVZs) - Growers of container ornamentals do not come within the scope of NVZs but growers within these areas should aim to minimise nitrate leaching to avoid future legislation.

Horticultural enterprises should be seen to be minimising nutrient and pesticide run-off in order to prevent the imposition of heavily enforced legislation in the future.

Action Points for Growers

It is recommended that growers calculate their own level of efficiency of water and fertiliser use. This can be done by following the procedure below:

1. Select a production area that you would like to test and calculate the number of plants in the area.
2. Weigh 20 plants, immediately prior to an irrigation, and record the weights.
3. Attach a water meter to the irrigation system (available from LBS Horticulture or LS Systems) to measure the quantity of water applied to the test area. In some cases it may be difficult to attach a meter in which case an alternative method of calculation will need to be used.
4. Apply the irrigation and record the quantity of water applied.
5. Re-weigh the 20 plants 30 minutes after the irrigation. Note that longer may need to be allowed for crops grown on capillary matting where water uptake takes place over an extended period.
6. To calculate the quantity of water applied to each plant divide the total quantity of water applied to the test area by the number of plants in the test area.
7. To calculate the quantity taken up by each plant subtract the pre-irrigation weights from the post-irrigation weights and calculate the mean uptake.
8. To calculate the quantity of water lost subtract the quantity taken up by each plant from the quantity applied to each plant.

Once this calculation has been done the system should be assessed, with staff involved in irrigation, to formulate a strategy to improve efficiency. The system can be re-tested later in the season to assess progress. In addition growers can carry out a simple water audit of the nursery to assess the potential for collection of roof water and run-off for use in irrigation. This may include a feasibility assessment for slow sand filtration or other forms of water treatment. Some key points from this research are highlighted below:

- Capillary irrigation systems are not necessarily efficient in their water use. Their efficiency depends on how they are managed. This research has highlighted the value of 'little and often' water application on capillary systems.
- Drip irrigation is very efficient and the costs of installation and management may not be as high as many growers would expect.
- Growers should assess whether they are compliant with current environmental legislation and implement measures to ensure they continue to be.
- Growers should analyse water quality to assess the content of the irrigation water and run-off leaving the site.

Anticipated Benefits

Making the relevant changes to production systems can greatly reduce water and fertiliser losses. The research has shown the potential cost of fertiliser losses and highlighted that it makes sound economic sense to assess current practice. By making simple changes, as recommended in this report, growers can reduce water and fertiliser costs, ensure legal compliance, keep within the requirements of the 'Water Code' and become more 'environmentally friendly' and therefore more likely to satisfy customer demands both now and in the long term.

1. INTRODUCTION

Growers are under increasing pressure to reduce water and fertiliser losses. These pressures are from four main sources:

- Government legislation
- Customer demands and accreditation schemes
- Rising water cost
- Environmental legislation and pressure groups

Until now the main pressures for any auditing of business processes have been from retail customers, particularly the major multiple retailers. Cost has also been a driving factor for growers reliant on mains supplies where water costs can be greater than £1/m^3 in some regions. However, growers are now facing pressures from legislation. Growers abstracting water from surface water or boreholes will need to justify their water use and demonstrate efficiency to be allowed to retain abstraction licenses. In addition, pollution legislation is likely to affect growers with nutrient-contaminated run-off if the industry does not act now to improve efficiency.

The objectives of this project were to quantify water and fertiliser losses from different production systems by carrying out efficiency tests on a number of UK nurseries growing Poinsettias during the 1999 season. These tests involved single irrigation measurements as well as detailed monitoring of water use on a number of Poinsettia crops throughout the whole production period. Poinsettias were selected as a relatively standard crop grown on a range of systems over a long production period.

The objectives of this project were:

- To quantify water and fertiliser losses from systems used in the production of protected ornamentals
- To outline clear measures for improving water and fertiliser use efficiency
- To aid compliance to legislation and reduce the likelihood of rigid future legislation
- To compare costings for different irrigation systems
- To enable growers to implement simple measures to improve practice

Wastage of water and release of fertiliser to the environment cannot be justified and most growers can implement simple measures to greatly reduce losses and in turn reduce the threat to the environment.

2. OVERVIEW OF RESEARCH WORK AND PRACTICES IN WATER AND NUTRIENT USE IN ORNAMENTALS

2.1 Review of Experimental Work

Comparing and Improving System Efficiency

Considerable amounts of research have been carried out in countries where growers are coming under pressure to reduce water and fertiliser wastage and losses. These countries include The Netherlands, Germany, Denmark, Israel, Australia and certain states within the USA. The issues faced in some of these countries are outlined in Section 5. Much of the recent European research has been based on 'closed' production systems. This is due to legislation imposed to eliminate nutrient run-off from nurseries as described in Section 5.

Most UK growers should be considering how they might reduce wastage of water and fertiliser and the first step should be to improve their irrigation system. Many European growers have eliminated this loss of water to the environment and are now looking at how to reduce water and fertiliser use by the adoption of 'closed' cropping systems.

Water Use Efficiency

Work in Australia (Hall *et al.*, 1998) compared levels of leachate leaving the following different irrigation systems:

a) Constant flow capillary matting (drippers constantly applying water)
b) Intermittent flow capillary matting (cycles of 4-6 minutes/hour for 12 hours followed by 4-6 minutes/2 hours for the next 12 hours)
c) Ebb and flow (flood to drainage hole height 2-3 times/day)
d) Overhead sprinklers

The following plant species were tested: *Artemesia* 'Powis Castle', *Coprosma kirkii*, *Rhagodia spinescens*, *Hebe traversii* and *Heliotropium arborescens* 'Lord Roberts'.

Between 55 and 79% of the water applied by overhead sprinklers left as run-off. The recirculating systems saved 40-46% of the water that was used in the overhead system and this would have increased to 60% if the tank water had not been emptied between trials. There was little difference between the intermittent and constant capillary systems which had similar water uses to the ebb and flow system. The *Artemesia* and *Heliotropium* grew better with the sub-irrigation systems but there were no quality differences with the other species.

Morvant *et al.* (1997) compared capillary matting, ebb and flow, hand watering and microtube (drip) irrigation. *Pelargonium hortorum* 'Pinto Red' were grown in 15 cm pots (1270 ml) with three plants per pot. The water applied and run-off produced was recorded as shown in Table 1.

Table 1 - Water applied and run-off produced in systems tested by Morvant *et al.* (1997)

Irrigation system	Applied (L)	Run-off (L)	Run-off (as % of applied)*
Hand	148	52	35
Microtube	108	48	44
Capillary mat	278	88	32
Ebb and flow	116	8	7

*Column added by author of this report (not in cited reference)

Run-off was clearly highest in the capillary system and lowest in the ebb and flow. The microtube system showed a relatively high percentage of run-off even though total volume applied was comparatively low.

These systems were tested again by Morvant *et al.* (1998) under two watering regimes. Each system applied water at a daily regime or an intermittent regime (i.e. water applied as required). The plants watered daily were bigger and more lush but the quality was generally lower because the growth was weak. The daily regime used more water than the intermittent one due to higher evaporation levels. The intermittent system was more efficient with water use but the run-off produced contained higher nutrient levels. The hand-watering system produced shorter plants than the other systems and 33% of the applied water was lost as run-off. Capillary matting also showed a poor efficiency of water use and this was attributed to evaporation from the mat surface. This system is likely to be more efficient in regions where temperature and light levels are lower. However, cooler climates can also promote algal growth and encourage infestations of sciarid and shore flies on such mattings. The study concluded that nutrient-rich run-off is best reduced by daily irrigation with ebb and flow or microtube systems but that in areas where water shortage is the main concern then intermittent microtube is the best option.

Irrigation frequency has been investigated in a number of projects. Work by Tyler *et al.* (1996) compared 'little and often' regimes to those with fewer, more prolonged waterings on *Cotoneaster* and *Rudbeckia*. *Cotoneaster* plants were grown in 3.8 litre pots and given the following treatments:

a) 900 ml once/day
b) 450 ml twice/day
c) 300 ml 3 times/day
d) 150 ml 6 times/day

On the cyclic irrigation regime a one hour break was allowed between each watering. Treatments b-d showed a 38% improvement in application efficiency over treatment a. However, this work was carried out in the south east of the USA where temperatures can be considerably higher than in the UK.

Work by Groves *et al.* (1998) on the same crops showed that frequent water applications (2-3 times a day) of small volumes can improve irrigation efficiency by

27%. With this greater control of watering, CRF (controlled release fertiliser) levels could be reduced.

Current research at HRI East Malling in a MAFF Link project (number 201) aims to improve the control and efficiency of water use in container hardy nursery stock. The research has subjected three species, *Forsythia*, *Cotinus* and *Hydrangea* to water stress treatments. Results so far have shown that it is possible to achieve a 50% water saving (i.e. 50% of normal evapotranspiration) without reducing crop quality. Most UK nursery stock growers irrigate at 300-400% of the evapotranspiration demand (Cameron, pers. comm.). This research is demonstrating that there are potentially huge water savings that can be made in nursery stock production. The main limiting factor at present is that most nursery stock growers do not have the technology and facilities required to control water application in this way.

Reducing Fertiliser leaching

Reducing fertiliser leaching can present a problem. It has long been recommended that growers water pots with 10-15% more water than required to prevent a build up of nutrients in the container (Cox, 1996). Most growers probably considerably exceed this and therefore there is still potential for reducing this excess (leaching fraction) without risking salt build up. Schuch *et al.* (1995) indicated that fertiliser application to Poinsettias can be reduced by 50% by reducing fertiliser application and controlling irrigation.

Andersen and Wang Hansen (2000) grew *Weigela* 'Bristol Ruby' and *Campanula carpatica* 'Dark Blue' at three different ECs (electrical conductivity):

High	2000 μS/cm
Intermediate	1250 μS/cm
Low	950 μS/cm

Weigela were grown in 3.5 litre pots at a spacing of $11/m^2$ and *Campanula* were grown in 0.67 litre pots at $40/m^2$. The ECs of the compost solution were measured three times each week and the feed adapted accordingly. Fertigation was initiated when three of the five tensiometers used reached 50 hPa. Fertigation was applied for one minute. The nitrogen uptake by the *Weigela* crop, in the low and intermediate ECs was so efficient that N levels in the leachate were reduced. Only 3-6 KgN/ha were leached from these treatments compared with 40 KgN/ha from the high EC treatment.

N leaching from the *Campanula* crop was much higher, with leaching of 90 KgN/ha from the high EC treatment, 45 KgN/ha from the intermediate and 17 KgN/ha from the low EC treatment. These higher levels were due to greater N leaching during flowering when N is not taken up.

The only quality effects noted in the work were that growth was slightly limited in the low EC treatment on *Weigela*. The best fertigation treatment produced only 1.5 -10% leaching compared with 22-56% leaching observed on the same crops grown with CRF outdoors.

Controlling Water and Fertiliser Application

There are many ways of controlling irrigation and feed to ornamental crops. The work cited above shows how different uses of the same system can greatly improve efficiency. The research carried out in this project has shown large differences in watering efficiency between growers using similar capillary systems in the UK. The research shows that 'little and often' irrigation is often the most efficient use of water and leads to minimal leaching. Large infrequent applications tend to be very wasteful. For example Otten *et al.* (1999) tested the effect of fertigation frequency in ebb and flow systems. They found that the time *Ficus benjamina* plant roots were kept under water had little effect on actual uptake. Most water was absorbed within the first five minutes and there was no difference between flooding for five minutes or 30 minutes. Watering twice a week for 30 minutes was insufficient and watering four times a week for five minutes was far more effective.

Evapotranspiration was measured and it was calculated that 19-41% of water lost in evapotranspiration was actually lost in evaporation. Temperatures and light levels can have a significant effect on water use. With a knowledge of evapotranspiration levels as well as 'actual buffer capacity' (as defined by Otten *et al.* 1999) then minimum fertigation requirements for a particular medium can be defined.

Some workers have tried to produce models for irrigation requirements for specific crops, as Stanley and Harbaugh (1989) did for Poinsettia. However, although most tested varieties responded well, not all did and most growers would be reluctant to adopt a model that may not work on the varieties they grow. The measurement of soil moisture tension has already been referred to with the use of tensiometric equipment. If standards could be produced at specific tensions, in different media, for different crops, then there would be considerable potential for water and fertiliser savings.

Newman *et al.* (1992) used solid state tensiometer technology to maintain soil moisture tension at 1-5 kPa on Poinsettia 'V-14 Glory' over a 10-week period. Drip irrigation was used and the controlled plants were compared with plants grown with drip irrigation but based on a manually operated system. There was a 65% saving in the total water used in the computer controlled system and a mean weekly reduction in leachate of 98.6%. There was no measurable reduction in plant quality even though compost analysis showed higher EC levels in the plants held at 1-5 kPa.

The tension of 1-5 kPa is very low compared with other experiments where tensions have been imposed up to 18 kPa. Hansen and Pasian (1999) showed that water application to container-grown roses can be halved by keeping crops at medium tensions of 7-12 kPa compared with low tensions (i.e. 3-6 kPa). The tensiometers were not as effective on plants grown at 15-17 kPa and these high tensions seemed to produce a lower quality crop.

Work by Werkhoven and van Os (1998) and recent unpublished work by Voogt *et al.* (in press) used Time-Domain Reflectrometry (TDR) and Frequency-Domain (FD) dielectric sensors, in addition to tensiometers, for measuring soil moisture for developing fertigation strategies in glasshouse soils in The Netherlands. A fertigation model has been developed to apply water and fertiliser to soil-grown chrysanthemum crops, without generating run-off or leaching to ground or surface waters. These new technologies present new opportunities for measuring moisture levels in growing media compared to tensiometers which became commercially available 45 years ago (Hansen and Pasian, 1999).

2.2 Review of Practices in Water and Nutrient Recirculation

Background to European irrigation systems

Currently in the UK there are limited numbers of recycling systems used in protected ornamentals, whereas for edible crops such as tomatoes and peppers recycling systems are extensive and based on rockwool. Those systems used in ornamentals consist of either ebb and flow on benches or floors, channel systems or containerised units. All protected pot plant producers in Denmark and most growers in Holland, Belgium and Germany use ebb and flow systems when ornamental crops are grown under protection. The area of recycling systems in Holland in 1989 are shown in Table 2.

Table 2 - Breakdown of different ornamental recycling systems in Holland (after Annevelink, 1999) as a % in pot plant nurseries (1989)

Production System	**% in size class (m^2/nursery)**			
	<5000	**5-10,000**	**710,000**	**Comparison**
Ground	35	45	39	40
Concrete floor	5	12	18	14
Fixed bench	39	19	9	18
Rolling bench	15	15	13	14
Transport bench	2	5	18	11
Unknown	4	4	3	3
Total ha	182	252	483	917

The main methods of irrigation for containerised nursery stock and cut flowers in the UK is by overhead sprayline, whilst for pot plants and bedding plants, a combination of capillary matting plus seamless tubes are mostly used in the autumn. During the spring/summer overhead spraylines are widely used.

Ebb and flow systems give controlled application of water and therefore liquid feed and pesticides which are applied through the system, such as plant growth regulators and fungicides for controlling root pathogens.

Since the late 1960’s, Denmark, Holland and Germany have invested in systems of irrigation which allow measured water applications and therefore measured fertiliser and chemical application. In the 70's and 80's these systems became mobile and in the late 80's and early 90's they became mechanised, so that robots can now be used within the glasshouse to move plants around the system.

In the early 80's the governments of northern Europe within the EEC, introduced legislation which encouraged replacement of old structures and the incorporation of ebb and flow systems within the protected ornamentals sector. This initiative was to avoid leachate pollution into the surrounding land and water. Experimental work at Aalsmeer and Naldwijk in Holland, Aarslev in Denmark and German research stations aimed to look at the specific problems occurring with the commercial uptake of these systems. A recent publication by Annevelink (1999) has indicated the most effective commercial use for a transport system within the glasshouse. The system requires the glasshouse structure to be developed around the system, which is developed to produce one to three crops. Continuing changes in pot or pack or crop reduces the system efficiency. The implementation of EU directives in the UK has been less dramatic, as described in Section 6.

Water Use

Cut Flowers

Research on restricted water application has been carried out on chrysanthemums and has been shown to delay production and lead to variable quality, thus affecting the economics of this crop. Where the majority of flower crops are still grown in the ground, guidelines on the amount of nutrient each crop requires have been approved by the relevant authorities (as described in Section 5). In Holland and Germany recycling systems have been employed for production of Gerbera and Roses with the use of rock-wool and coir slabs.

Containerised Plants

Recycling systems have most potential in the production of "containerised" crops such as pots, packs, etc. However, where the packs or pots are high in density, the container impedes water application from the ends of a bench or bed. Therefore irrigation can either be from above, or if the packs and pots are raised off the bench or floor level, from below, so that the water level can be raised and water can run freely beneath the containers and enter the container and substrate.

Recycling Systems

There are three main sub-irrigation recycling systems:

1. Concrete floors
2. Transport tables
3. Troughs or channels

Installation of such systems requires high initial capital expenditure. The expenditure will depend to a greater extent on the size of the nursery and the facilities into which that installation is to be placed. In many UK nurseries, such installations would be uneconomic due either to the configuration of the original structure, or the building itself making the layout so obtuse as to render the efficiencies in water application and labour less viable and probably uneconomic. The best systems are installed on nurseries of one hectare or above with a flow pattern for a particular crop or crops of a particular container size.

The most successful crops produced in the UK under such conditions are ‘All Year Round’ crops such as pot chrysanthemums and *Begonia*. Seasonal crops such as Poinsettias, New Guinea Impatiens, *Osteospermum* and *Gerbera* can be grown successfully on these recycling systems. Changes in pot size may make certain crops more difficult to irrigate, particularly with small pots which may float away when dry unless held in tray containers.

The main problems with recycling systems are the need for the container, compost and the system to work in unison with the crop to avoid all mitigating factors which may affect quality or delay production time. These factors include compost and pots that seal the base and thus do not drain, or do not admit enough water. Root disease problems such as *Pythium or Phytophthora* can easily occur and spread in such a system. The local environment of the crop is changed by the ability to water and the ability to directly heat the floor or bench, thus compost temperature and moisture levels have become of greater importance. These factors can be maintained at 'optimum' for a crop whilst allowing the use of air temperature management to control plant height.

The main advantage of these systems is the control of water and fertiliser, reduction of pesticide loss and applying pesticides more accurately. In addition, these systems use a greater percentage of the floor area (up to 92%) when using 'double-decking' techniques or transport systems. Gers (1986) indicated two types of double decking, rotary and with tables. Rotary systems have now been superceded by tables which increase site use by up to 150%, thus allowing production peaks to be evened out.

In 1987 the Secretariat of the Dutch Horticultural Study (Anon, 1987) stated that "research must be a major concern for the ebb and flow committee". Research enabled modifications to be made to the microclimate in and around ebb and flow systems and monitoring whether the modifications affected growth, development and quality of plants. With trough or trough-like systems the air flow from below the trough was studied. Air currents and flows below the troughs were strongly influenced by the other air currents within the glasshouse, so it was difficult to achieve a uniform distribution of air between plants. Pot plants used in experiments included *Schefflera*, *Ficus*, *Spathiphyllum* and *Guzmania*. Research was requested on the control of *Fusarium* and *Phytopthora* within the system on cyclamen, *Peperomia* and *Gloxinia* respectively. At that time the Dutch researcher Rattink reported that no instances of spread of *Phytopthora* infection had been observed in the experimental ebb and flow cultures. This was because the prevailing systems provided good drainage and the spores were denied the time and opportunity to attach themselves to the roots in ebb and flow systems. The main priorities for the committee included research into the climate of ebb and flow concrete floor systems where dramatic decline in air humidity occurred in spring and summer.

Glasshouse design

Since 1987, the emphasis on glasshouse design has been based more on system requirements. Building glasshouses with extra height (4.5-5 metres) has helped to prevent poor air circulation in glasshouses where benches have reduced the height between the eaves and the top of the benches. Thus, although a recycling system has to be designed first and the house erected around it, improvements in house design are also incorporated.

Systems

Recycling systems (whether it be floor, bench or trough) require an even base on which the water can enter quickly, cover the whole area for ebb and flow systems and drain rapidly. For trough systems there is a different tube or channel for the water to enter at one end and flow away at the other, with container plants taking up the water as the water passes by. Water should remain on the surface of a system for as short a period as possible for water uptake, but generally no longer than 15-20 minutes.

The layout of any ebb and flow system will depend on the crop, the configuration of the land and the building structure. With bedding plants in packs, the system may need to have a facility to take the product outside on rails. This requires envelope doors at one end of the structure, normally the south end so that product can be "wheeled" out through the envelopes on the rails and tables. For pot plants, the actual configuration of the tables will depend on site, facility and cropping. The best site is going to be one of clean, level land. The system for transport tables can be static but is preferably mobile, when the product can be taken from the potting area, through the production system and return it to a harvest or storage area. Concrete floors must be laid out in a similar way, with road ways between them. On both table and floor systems, overhead cranes can be installed to move either product or tables.

With either system, plants grown in 9 cm or larger containers can be placed on the table or floor independently but with smaller plants, plugs, etc. plants will need to be contained in a tray. The plug trays should have ‘legs’. Benches can be double-decked either over the work area or amongst certain stages of crop production. The structure must have a minumum height of 5 m to the eaves.

Within the system it is possible, by optimising spacing, to increase plant numbers by up to 20%. This means that consecutive grading will give a better quality of plant at harvest.

Vegter (1988) indicated great support for concrete floors, despite the ergonomic drawbacks. He noted that concrete floors were developed for labour extensive crops with the use of robots for picking up and placing down. Benches are preferred for labour intensive crops.

Annevelink (1999) published tables which indicated the breakdown of different systems in Holland (see Table 2). Bakker (1988) indicated the criteria for floors: (these are listed in Appendix I) and stated that installation of below floor heating systems depended on the energy costs.

Heating

In each method of irrigation the heating system needs to be in place where it is most effective, i.e. with floors it should be built into the floor and each floor section temperature controlled. With benches, the heating system can be applied directly underneath and often as a separate system for the whole heating of the house. In some early trough designs the heating system was placed alongside each line of troughs. The bench type may prevent good heat distribution (e.g. if it has a plastic top rather than a metal top). If the tables are closed up to gain production within the house, the only penetration of heat will be through the base of the bench. Plastic bottoms to benches act as insulation, which may mean the benches do not dry rapidly nor does the required heat pass through to the compost in the container. With metal benches, i.e. aluminium, when heat demand is high, strips of drier areas of containers are likely to occur. Where bench edges are exposed the heat is likely to cause those plants and containers to dry more rapidly.

The LVG Wiesbden reported that cyclamen cultivated in channels achieved higher quality than was previously possible by conventional methods (i.e. capillary matting) (Harmer, 1990). Tensiometers fitted to automatic irrigation indicated different growing substrates can give better results (i.e. traditional compost with the addition of 10-20% aggregate material such as perlite, rice husk or coconut fibres gave better growth on crops such as the *Gesneriaceae* family).

High pot density will also cause extremes in microclimate in small areas. When the crop is pot-thick or at full canopy cover, the humidity and temperature within the crop are likely to be very high, 100% RH can occur in these cases. Once the crop is spaced the humidity levels will be lower until full canopy cover occurs. This dynamic and changing microclimate affects both plant pest and disease levels, as well as water use and therefore fertiliser application and nutrient uptake.

Water Quality

Water quality is of the highest importance in recycling systems as the same water will, with top-up water, be recycled continuously for several months. The water should be free of extraneous nutrients such as sodium, chloride and sulphates and have sufficiently low alkalinity. When water with high levels of alkalinity and salts is used, then fertiliser rates must be adjusted accordingly to meet the requirement of the crop at each particular growth stage. Where high levels of extraneous salt occur, the solution must be changed more often, otherwise plant growth will be impaired or delayed, with a consequent economic cost.

Media and Containers for recycling water systems

The container used for a recycling system needs to be designed so that the water can enter and drain from the container evenly and quickly. The container must be strong enough so that the holes at the bottom of the container allow drainage whilst also allowing water to be taken up. Too dense a substrate may reduce the quantity of water entering or exiting through the holes. A pot with only basal drainage can often cause a film of moisture which does not permit good entry or exit of water.

The substrate should be open but also moisture-retentive. Substrates which allow a build up of fine particles in the base of the pot should be avoided. When the crop is newly potted and has reached canopy cover, evaporation from the surface of the compost can be great and in such cases a build up of salt can occur in the top centimetre of compost. Additives to the compost such as bark, Perlite, coir or wood fibre can be used to improve the relevant media properties.

Nutrition

Nutrition in a recycling system requires the compost to be pH-adjusted to the requirements of that crop and then a fertiliser applied which is appropriate for the water supply and crop. Thereafter, continuous application of fertiliser can be applied according to EC and salt content of the water supply.

Economic Factors

These systems have been used for temperature modelling experiments at Aarslev in Denmark, in a three year programme starting in the winter of 1999/2000. Work has indicated that using controlled irrigation systems, a heat saving of 30% can be achieved, without affecting financial returns. Private enquiries have indicated that the 30% energy saving is being spent on increased lighting to raise the light levels on begonias from 30-40 W/m^2 to 70 W/m^2. On recycled systems this increases the winter quality of the product.

Water Use

Recycling systems can reduce water use by 30% or more over normal irrigation systems such as capillary matting and overhead application. The use of compost moisture measurement equipment has enabled further savings by applying water as the plants require it, rather than by computer clock, e.g. field-grown hydrangeas in Anger (Calopin, pers. comm.) and research by Hendriks (Hendriks, pers. comm.) on Poinsettias at Geisenheim indicated a saving of up to 25-30%. Research with the Frequency Domain (FD) monitoring equipment and the overall monitoring of water supply as plants require it has been carried out at Aalsmeer (Baas, pers. comm.).

Pest and Disease

The most common disease problems associated with recycling systems are *Pythium*, *Phytophthora* and *Fusarium.* Opportunist pathogens are likely to increase the incidence of these diseases if the system is poorly designed or if the compost or container are not of the quality required as previously discussed. *Pythium* and *Phytophthora* can be re-cycled around the system within the water. Large holding tanks allow *Pythium* and *Phytophthora* spores to sink to the bottom. Thinggaard and Middelbore (1989) reported high isolates of *Pythium* on *Gerbera* and regard control of *Pythium* and *Phytophthora* as important in plant health. According to Wohanka (1984) these problems could be reduced if compost and nutrition met the best specifications. Water sterilisation will also reduce pathogen levels in the system.

Summary

Recycling systems not only save water, fertiliser and pesticide but if set up properly and mechanised, they dramatically reduce labour input per unit of production. Savings in the production phase can be as high as 30%. By keeping the crop to the maximum density before spacing, the use of water, light and CO_2 will also be optimised and this further increases crop throughput. Problems develop from using poor equipment within the system, (e.g. pot, substrate, etc.). The need for high water quality to maximise plant growth and reduce the disposal of water is important. Computerised management of the system enables accurate crop programming.

3. EVALUATION OF THE EFFICIENCY OF WATER AND FERTILISER USE IN DIFFERENT PRODUCTION SYSTEMS FOR PROTECTED CONTAINER ORNAMENTALS IN THE UK

The objectives of this project were to quantify water and fertiliser losses from different production systems by carrying out efficiency tests on a number of UK nurseries growing Poinsettias during the 1999 season. These tests involved single irrigation measurements as well as detailed monitoring of water use on a number of Poinsettia crops throughout the whole production period. Poinsettias were selected as a relatively standard crop grown on a range of systems over a long production period.

The experimental work was divided into two stages as follows:

3.1 Materials and Methods

Stage 1 - System Tests to Evaluate the Variation in Water and Fertiliser Use Between and Within Different Growing Systems on Commercial Nurseries

Identification of Nurseries and Systems

The primary objective of this stage was to establish the degree of variation of water loss between and within different growing systems. It was decided that, in order to reduce the number of variables affecting results, one crop should be selected. The crop selected was Poinsettia 'Sonora'. This crop is widely grown across the UK using a range of different irrigation systems. By selecting one crop the research would be comparing like with like across the different systems, as crops would be at similar stages of growth and development throughout the country.

Seven irrigation systems were identified as being the most widely used systems for production of protected ornamentals. These were as follows:

- 'Ebb and flow' flood benching
- Overhead gantry (application usually to capillary matting)
- Hand-watering (using hosepipe)
- Capillary (various systems using capillary principles)
- Drip / trickle
- Overhead spraylines
- Trough track

It was not possible to identify growers producing a standard crop (i.e. Poinsettia) using all these systems. However, the following systems and nurseries were identified:-

Nursery	System
Ebb A	Ebb and flow flood benches 7m^2 (recirculating). Flood for 4-8 minutes depending on crop demand.
Ebb B	Ebb and flow flood benches 7m^2 (recirculating). The bench is covered

	with thin capillary matting overlaid with perforated polythene. Flood for approximately 6 minutes depending on demand.
Ebb C	Ebb and flow flood benches 10m^2 (recirculating). Flood for 12-15 minutes.
Ebb/cap D	Flooded capillary matting on benches (recirculating). Water is released onto one end of the bench and allowed to flood the bench. Capillary matting on the bench helps to retain some water after the flooded water has drained away.
Cap A1	Sand base on the ground overlaid with polythene, overlaid with capillary matting overlaid with perforated polythene. Trickle tape pipes (outlets every 20 cm) are used to apply irrigation at 9-15 minute sessions depending on crop demand.
Cap A2	Open mesh based benches (8.8 m^2) covered with polystyrene overlaid with polythene overlaid with capillary matting overlaid with perforated polythene. Benches are on a slight gradient. Water is applied at the top of the bench (7-9 minutes) and allowed to drain down the bench through the matting.
Cap B1	Open mesh benches (20m^2) covered with polystyrene overlaid with polythene overlaid with capillary matting overlaid with perforated polythene. Irrigation is applied by 'spaghetti' pipes feeding directly onto the bench at the base of plants. Irrigation is applied for approximately 30 minutes.
Cap B2	Sand base on the ground overlaid with perforated polythene overlaid with capillary matting overlaid with 'Mypex'. Trickle tape pipes (outlets every 30 cm) are used to apply irrigation for 1-2 hour sessions depending on crop demand. This high volume acts as a 'flooding' system although excess water is not collected and drains into the ground.
Cap C	Polythene covering on the ground overlaid with capillary matting. Irrigation is applied by a combination of trickle tape pipes and hand watering.
Cap D	Plants individually placed in saucers with trickle pipe laid across the saucers. The saucers are spaced to coincide with the drip outlets on the trickle pipe.
Cap E	Plants standing on open mesh benches overlaid with capillary matting ('fleece'). Irrigation is applied by an overhead gantry with nozzles directed beneath the foliage to the matting.
Tric A1	Irrigation applied by pressure compensated drippers to each plant.

Tric A2	Irrigation applied by pressure compensated drippers to each plant (same as A1 but repeat test after some improvements had been made).
Tric B	Irrigation applied by drippers to each plant.
Tric C	Irrigation applied by drippers to each plant.
Trough A	Plants spaced in troughs with a single pipe supplying water to each trough. Irrigation is on for approximately 11 minutes depending on crop demand. Unused irrigation water drains off the end of the trough onto concrete or bare soil below.
Hand A	Sand base on the ground overlaid with 'Mypex' overlaid with capillary matting overlaid with perforated polythene. Irrigation is by hosepipe with lance.
Hand B	Plants spaced on heated benches overlaid with polystyrene overlaid with polythene overlaid with capillary matting overlaid with perforated polythene. Irrigation is applied by a hosepipe with lance.
Hand C	'Mypex' over the ground. Irrigation applied by hosepipe.
Hand D	Plants individually placed in saucers and watered by hand directly into the saucers.
Spray A	Boom with spray nozzles was passed over the crop 8 times. Plants were standing on mesh benches overlaid with polythene, fleece and microperforated film.

In order to assess the comparative efficiency of each system the following test protocol was developed:

The Irrigation Test

All the selected nurseries (as described above) were visited during week 38 of the 1999 Poinsettia growing season. On each nursery a specified area of crop was irrigated. The area to be irrigated was measured and the exact number of plants and spacing was recorded. Twenty plants were randomly selected from the area and weighed using electronic scales accurate to the nearest gram. Weighed plants were labelled 1-20 and weights were recorded.

Following weighing the irrigation was applied as per standard nursery practice. The volume of water applied to the designated area was calculated. The method for this calculation varied depending on the system. On some systems (Ebb/cap D, Cap B1, Cap D, Cap E, Hand A, Hand B, Hand C, Hand D) it was possible to install a water meter (3/4 inch and 1 1/2 inch meters from LS Systems, Preston and LBS Horticulture, Colne). Different methods were employed in other systems where the fitting of a water meter was not practical. For example water was collected from drippers in drip trickle pipe systems and bench volumes were calculated in ebb and flow systems.

The twenty numbered plants were re-weighed 30 minutes after the irrigation had ended (or after water had drained from ebb and flow systems) and weights recorded. From this it was possible to calculate the quantity of water applied to each plant, the quantity taken up by each plant and therefore the quantity unused (most of which was assumed to be run-off).

The test was carried out once on each of the systems listed above during week 38. The plants irrigated were at a stage of dryness at which the nurseries involved would have irrigated (i.e. the tests were not carried out on plants that did not need irrigating).

Details of the production system were recorded as well as comments on crop quality, growing media type, spacing and pot size (all 1 litre volume pots). Notes were made on the fate of run-off from each system and any other relevant details which may affect the interpretation of results.

Growing Media

It is likely that the nature of the growing media used by each nursery will affect water uptake, leaching and water usage figures. To assess the effect of media the nature of the media was recorded on site. In addition, five plants from each nursery were selected randomly from the tested area. The foliage part of the plant was removed leaving the roots and growing media intact in the pot. These pots were then sent for laboratory analysis of Air Filled Porosity (AFP) and particle size.

AFP Method

In order to get an estimate of the physical structure the Air Filled Porosity (AFP) of peat or compost can be measured. This is a measure of the air space that remains after a compost has been immersed in water and completely wetted and then the excess water allowed to drain off under gravity. The method used complies with BS 4156. The method used for the determination of the AFP of the samples is that developed by Bragg and Chambers (1987) and adopted by the then government advisory service ADAS for the differentiation of mixes depending on their base ingredients. The methods and modification of it have been widely used and it is accepted that for mixes varying in more than 4% AFP , then the method can reliably be used for differentiation.

The pot (standard tapered plastic pot, height 12 cm, top diameter 13 cm, base diameter 9 cm) whose internal volume has been accurately determined (1150 ml) plus compost is placed in a water bath and gradually wet from below, ensuring that the water level is sufficiently high to cover all the compost.

After initial wetting, the pot and compost are removed from the water bath and allowed to drain for 10 minutes. This completes one wetting and draining cycle; three wetting and draining cycles are carried out in total. The top of the pot is then covered with nylon gauze and secured by an elastic band.

The pot is placed on a ceramic tile in the water bath and saturated from below, adjusting the water level in the bath to that of the compost surface. When the compost is thoroughly wetted (water can be seen on the surface of the nylon gauze), the pot is slid off the tile onto a rubber (neoprene) sealing pad. This should be pressed firmly onto the pot base providing a water tight seal, and the pot transferred to a funnel on the drainage rack. The pad is then removed and the compost allowed to drain into a beaker for 30 minutes. The volume of drainage water is measured, and the AFP expressed in volume percentage terms.

Particle Size Analysis

Particle size analysis was determined as follows. On completion of the AFP test the samples were dried until approximately 20% moisture is retained. Each sample was then passed through a column of nine sieves (300 mm diameter) with mesh sizes of 13.2, 6.7, 4.75, 3.4, 2.0, 1.0, 0.5 and 0.1 mm. A pan was placed on the base to collect the finest particles.

The top of this column was covered with a lid and the sieves were shaken manually for approximately 15 minutes until a constant amount of peat was retained on each sieve. The sieves were then weighed and the amount of peat retained on each sieve was calculated. This figure was then converted to percentages of the total weight of the initial sample.

All the samples for the main monitoring sites were also sieved and in Appendix 20 the percentage of <2mm particles is plotted against AFP. The reason the less than 2mm particles were selected is that Scharpf (1997) attached high significance to increasing <2mm size particles and low AFP's.

Water Quality and Composition of Run-off

Water samples were taken at each test nursery and analysed for nutrient content (using ADAS Hydroponic water analysis) at the ADAS Laboratories, Wolverhampton. Where possible samples were taken of:

- Untreated water (i.e. borehole or mains water)
- Irrigation water (i.e. usually included liquid feed)
- Run-off

Costs of each System

Costings for a typical example of each of the seven initially identified systems was carried out. This is to include the cost of setting up and maintaining each system. Results can be seen in Section 4.2.

Stage 2 - Measurement of the Efficiency of Water and Fertiliser Use in Different Production Systems for Poinsettia throughout the Duration of the Crop

This stage extended the work in Stage 1 to enable the calculation of water and fertiliser use in four production systems throughout the production of a Poinsettia 'Sonora' crop from potting to sale. The four nurseries selected for this test were as follows.

Nursery	**System**
A	Ebb and flow flood benches 10m^2 (recirculating). Flood for 12-15 minutes per irrigation.
B	Flooded capillary matting on benches (recirculating). Water is released onto one end of the bench and allowed to flood the bench. Capillary matting on the bench helps to retain some water after the flooded water has drained away.
C	Plants standing on open mesh benches overlaid with capillary matting ('fleece'). Irrigation is applied by an overhead gantry with nozzles directed beneath the foliage to the matting.
D	Plants spaced on heated benches overlaid with polystyrene overlaid with polythene overlaid with capillary matting overlaid with perforated polythene. Irrigation is applied by a hosepipe with lance.

Calculating Water Application

As with Stage 1, the water applied to a designated area of production was calculated. Water meters were used for nurseries B, C and D to record the volume of water applied through the season. Each nursery recorded the reading on the meter after each irrigation. The ebb and flow benching system in nursery A operated at a pressure greater than the water meter was designed for. On this nursery a designated staff member recorded the number of minutes that each flooding was on for and the date. At various times through the season the quantity of water applied to each bench was calculated by collecting the water applied in a measuring tank. For each nursery accurate figures were produced for water application through the season***. It is important to note that nurseries A and B recirculate unused water and therefore it is not wasted or lost as run-off***. However, other growers operate similar systems which are not recirculated.

Calculating Water Uptake by the Crop

To calculate crop uptake the irrigation tests (described for Stage 1) were repeated at fortnightly intervals from week 34 - 46. Twenty plants were numbered and weighed before and after irrigation during these tests (the same twenty plants each time). By calculating the mean water uptake across the irrigations through the season it is possible to get an estimate of the quantity of water taken up by the crop and the quantity unused or recirculated.

Calculating Fertiliser Application and Uptake

All participating nurseries applied fertiliser as liquid feed during irrigation. The quantity of fertiliser applied was calculated either by using the stock solution recipes and dilution factors, or, on systems making application by measurement of EC (i.e. nurseries A and B), by using the water analysis results for the irrigation applied. Total quantities of fertiliser (N, P and K) applied can be calculated for each of the nurseries.

Fertiliser uptake was calculated using laboratory testing at the ADAS Laboratories. At potting, 20 plugs from each nursery were analysed for fresh weight, dry weight, dry matter, calcium, magnesium, phosphorus, nitrogen and potassium. The whole plant was analysed, including the roots, but not the growing media. This figure quantified the nutrient content of the plants at the start of the work. This analysis was repeated on 10 plants from each nursery at the point of sale to give the nutrient content at the end of the production cycle.

Throughout the growing season the four nurseries participated in the 'Poinsettia Monitoring Scheme' operated by Bulrush Peat Company Ltd. This involved the submission of leaf samples to Natural Resource Management (NRM) Laboratories for analysis of tissue nutrient content. The results were used to compare nurseries participating in this research with other nurseries participating in the monitoring scheme, to ensure that those involved in this project were typical of industry standards.

Water Quality and Content

As with the tests in Stage 1, samples were taken of irrigation and run-off (where possible) water. This data can be used to assess nutrient losses and assess the potential environmental impact of the run-off.

The Growing Season

Different growers have different practices in terms of production techniques. Each of the four nurseries kept a 'Crop Diary' where any operations that affected the crop, (e.g. spacing, pesticide applications, changes in liquid feed) were recorded. Water application is also affected by light and temperature levels through the season. Light levels were recorded for each of the different locations to see how these relate to the water use results.

Growing Media

As with Stage 1 the growing media was analysed for AFP and particle size at the start and end of the growing season. Ten plants were analysed at both the start and end from each nursery using the methods as described in Stage 1.

Crop Quality

The quality of the crops produced on each nursery was assessed according to the protocol for project PC 156 (HDC funded Poinsettia variety trialling). This was carried out to ensure that water and fertiliser applications by each of the nurseries, was sufficient to ensure plants of acceptable quality.

Options for Run-off Management

Options for the collection and re-use of run-off were evaluated.

3.2 Results

Stage 1 - System Tests to Evaluate the Variation in Water and Fertiliser Use Between and Within Different Growing Systems on Commercial Nurseries

Irrigation Tests

Tests were carried out according to the method as described. Figure 1 shows the fate of water applied during the irrigation test in each system.

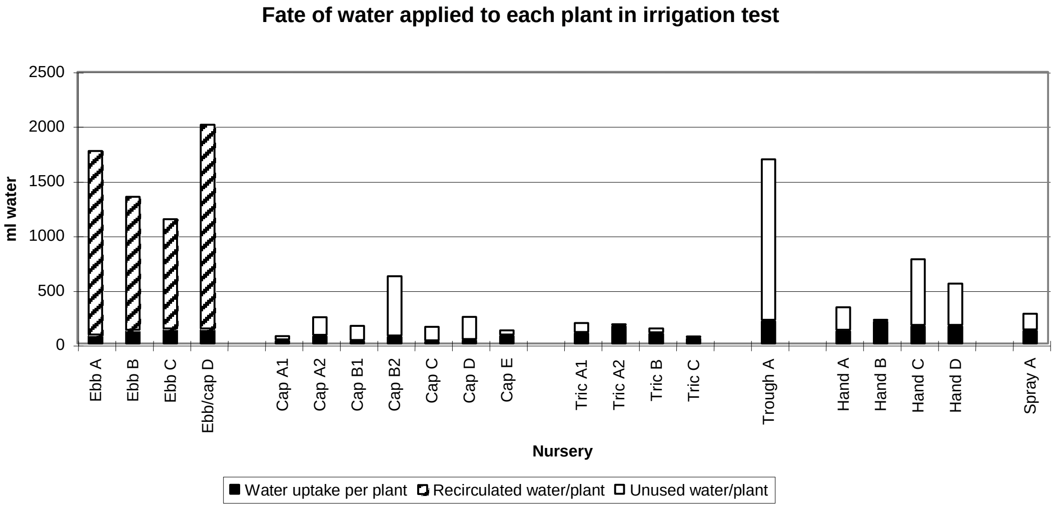


Figure 1 - Fate of water applied to each plant in the irrigation tests (1000 ml = 1 litre).

Full details of the results of the tests are shown in Appendix II. These results can be extrapolated to give an estimation of water use and loss through the whole season. Water uptake levels did vary between systems. To carry out this extrapolation the following method was used:

- The total uptake per plant was assumed to be 5.5 litres through the season on each nursery. This figure was the average uptake figure recorded on the Stage 2 nursery tests.
- This figure was then divided by the volume of water recorded to have been taken up during the irrigation test. The resulting figure gave the number of irrigations that would be required to supply each plant with 5.5 litres of water.
- The figure for the number of irrigations required was then multiplied by the quantity of water applied at each irrigation (based on the irrigation test measurement). The resulting figure was the amount of water assumed to have been applied to the crop through the season.
- 5.5 litres was then subtracted from this figure to give the total water lost (or recirculated) through the season.

The following assumptions were made in making this extrapolation:

- The total uptake for each plant on all nurseries was 5.5 litres through the season.
- The same amount of water was applied at every irrigation as was applied during the irrigation test.
- Plant uptake per irrigation was the same at each irrigation.

Clearly this would not always have been the case and the true values may vary from the extrapolated figures. This is highlighted by the way the figures for Ebb C (Nursery A in Stage 2), Ebb/cap D (B in Stage 2), Cap E (C in Stage 2) and Hand B (D in Stage 2) differ from the recorded values for Stage 2 tests (Figure 7). However, despite these limitations it was felt that the information showed clear enough trends to warrant inclusion in the report and provides a guide to the variation in water losses between different production systems. Figure 2 shows these extrapolations.

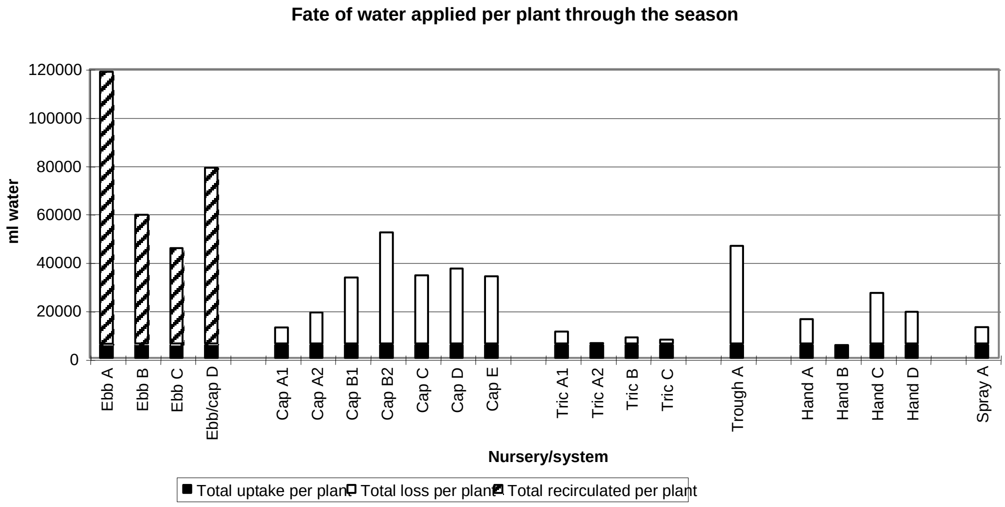


Figure 2 - Fate of water applied to each plant through the production season (1000 ml = 1 litre).

These figures highlight the potential use and wastage of large quantities of water in many production systems. For example, for every plant grown in Trough A nursery 41 litres of water could be lost from the system during the production season. For a nursery growing 10,000 Poinsettias on this system they should expect to be wasting 410,000 litres (410 m^3) of water. The Cap B2 system would be losing 46.5 litres per plant which is equivalent to a loss of 465,000 litres (465 m^3) water on 10,000 plants.

However, some systems were much more efficient in water use, particularly the trickle systems. System Tric A2 lost only 0.7 litres per plant through the season which is equivalent to a water loss of only 7000 litres (7 m^3) if 10,000 plants were grown. A more detailed analysis of these differences is presented in Section 3.3.

Growing Media

Growing media was analysed at most (plants were not made available for this test on all nurseries) of the nurseries tested. Results of the analysis, for AFP and particle size, are shown in Appendix VI. AFP levels were generally low which reflected the quality of peat used during the 1999 season from the wet 1998 harvest. Results are summarised in Figure 3.

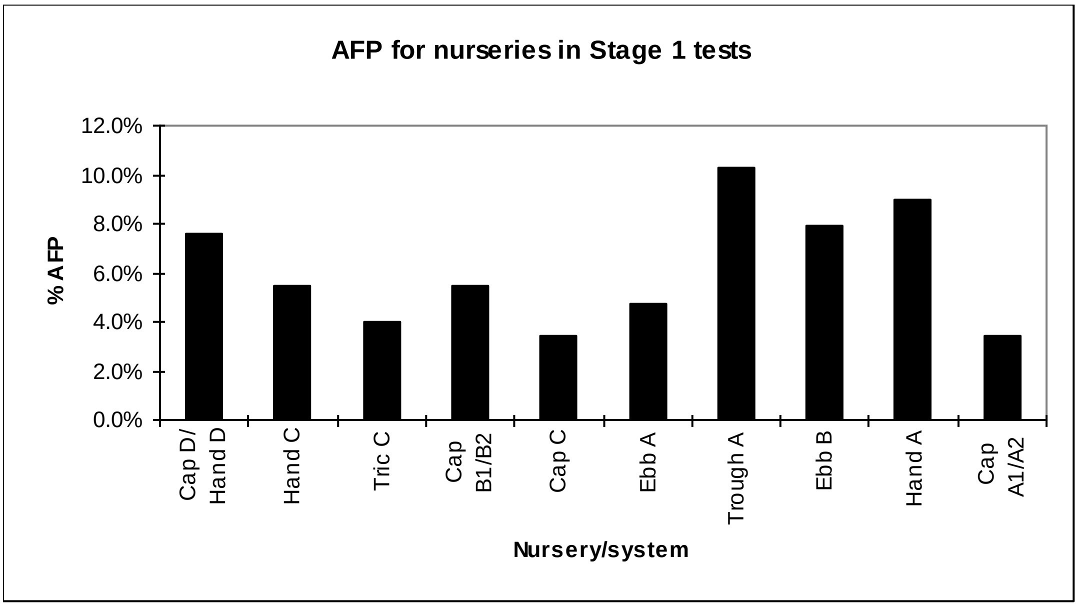


Figure 3 - AFP results for nurseries in Stage 1 tests.

Water Quality

As stated in Section 3.1, water samples were taken of untreated water, water applied to the crop (i.e. including liquid feed) and run-off where possible. The results are shown in Appendices III to V and results for total nitrogen (nitrate-N) are shown in Table 3.

Table 3 - Nitrogen levels in analysed water during week 38

Nursery	**N mg/l**		
	Untreated	**Irrigation**	**Run-off**
Trough A	1.1	93.5	115.4
Ebb A	1.6	38.3	no sample
Ebb B	11.1	54.2	51.5
Ebb C	12.2	101.3	91.9
Cap A1	0.0	44.9	5.6
Cap A2	0.0	no sample	5.6
Cap B	0.7	40.3	69.2
Cap C	1.8	46.3	29.6
Ebb/cap D - borehole	8.1	64.3	61.1
Ebb/cap D - mains	2.3	64.3	61.1
Cap E	no sample	11	no sample
Tric A	1.1	25.2	no sample
Tric B	0.0	85	no sample
Tric C	0.0	38.7	no sample
Hand A	2.3	25.5	23.7
Hand B	5.0	121	149
Hand C	2.3	51.2	85.1

Stage 2 - Measurement of the Efficiency of Water and Fertiliser Use in Different Production Systems for Poinsettia throughout the Duration of the Crop

Total Water Application

The quantities of water applied to the designated test area was calculated. This was then divided by the number of plants in the test area to give quantities of water applied to each plant through the growing season. Figure 5 shows the total water application to a single plant in the different systems. N. B. water applied in nurseries A and B was recirculated and therefore surplus water was **not** wasted.

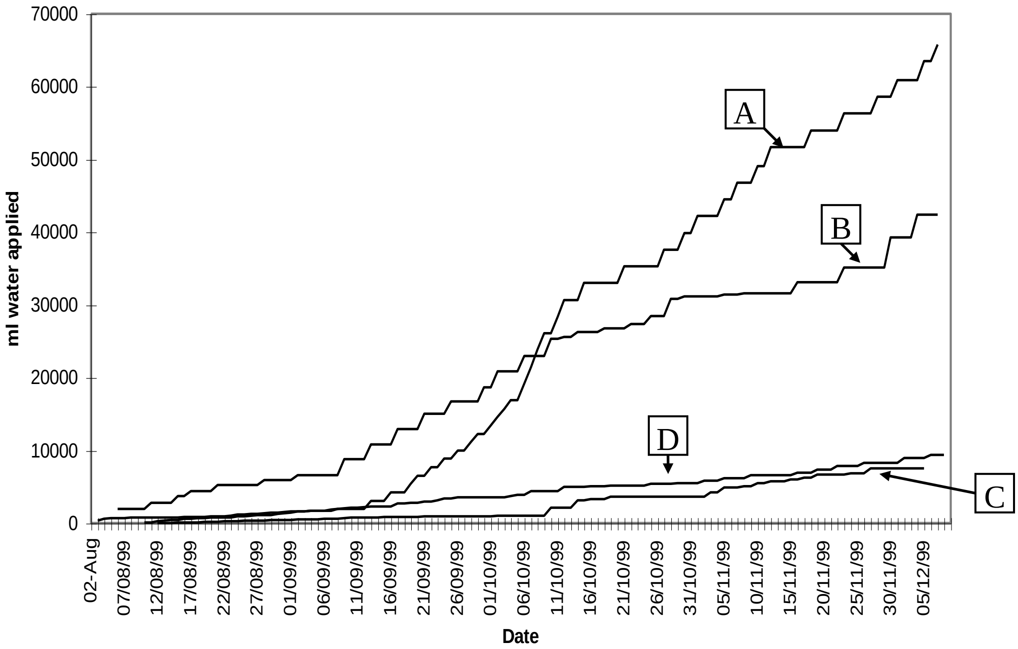


Figure 5 - Chart to show the quantity of water applied to each plant through the production season on the four nurseries A to D. Note that the figures are cumulative and not actual for each date.

Further details of water use through the season are shown in Appendix VI and VIII.

Water Uptake by the Crop

The irrigation tests were carried out on seven occasions through the growing season. Plants were weighed before and after each irrigation. The difference in weight represents the quantity of water taken up by the plant. The data collected in these tests is given in Appendix VII. As each nursery irrigated at different moisture levels, the uptake at each irrigation varied both between nurseries and between irrigations. Figure 6 shows the mean water uptake on each nursery at each irrigation. The error bars show the range (i.e. minimum and maximum) of mean uptake values.

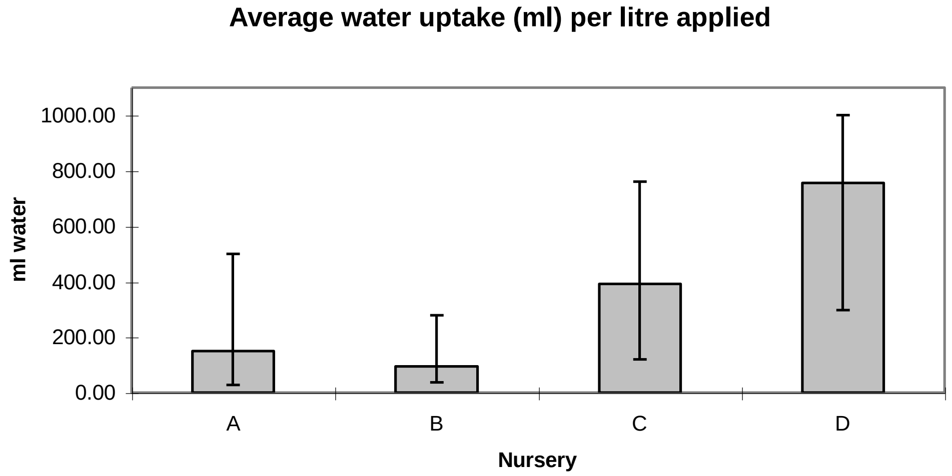


Figure 6 - Average water uptake by each plant per litre applied to the crop per irrigation cycle.

Lost Water

From an understanding of the water applied and the water taken up by the crops it is possible to calculate the quantity of water that is not taken up by the crop. Some of this water is lost through evaporation and some will be held for a time in capillary matting where this is used. However, the majority of unused water is lost as run-off. Water use and loss can be estimated for the whole production season for the 1999 Poinsettia crop. Total uptake of water per plant throughout the production season can be estimated by taking the mean uptake at each irrigation (Figure 6 above) multiplied by the number of irrigations. The fate of water applied throughout the season on different nurseries is shown in Figure 7.

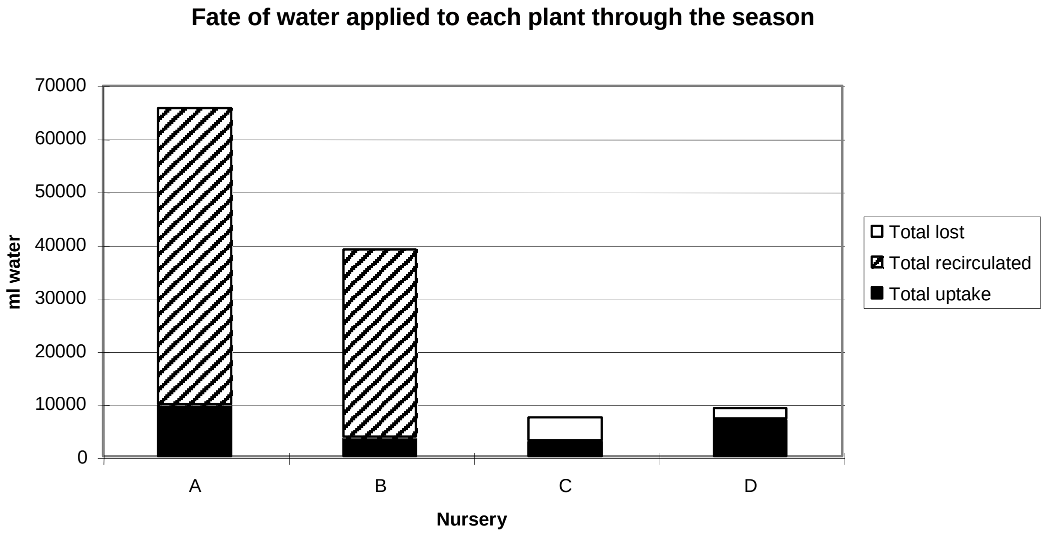


Figure 7 - Fate of water applied to each plant in the tested systems throughout the production season (1000 ml = 1 litre).

Based on a mean cost of mains water of £0.67/m^3 the cost of irrigating 10,000 plants would be approximately £66 for nursery A, £25 for nursery B, £51 for nursery C and £63 for nursery D. The cost for water application for nurseries A and B has taken the water uptake figures as a baseline. It is necessary to do this as the unused water is recirculated in these systems. The recirculating nursery B costs the least to run, in terms of water and fertiliser costs. The apparently high cost for nursery A is due to the high levels of water uptake by the crop on this nursery.

Fertiliser Application and Uptake

Appendix XV shows the nutrient status of the crop before and after the tests as well as the quantities of fertiliser applied. Figure 8 shows the different levels of nitrogen application and loss from each system.

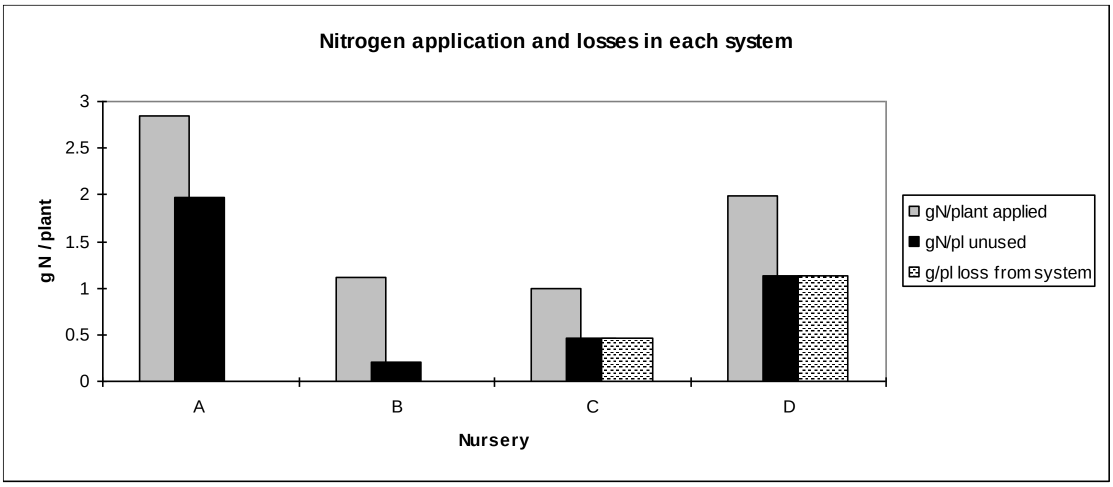


Figure 8 - Quantities of nitrogen applied and lost from each of the systems tested.

There is no nitrogen loss from systems A and B as they are recirculating systems. However, unused nitrogen in nurseries C and D would have been lost from the system, largely in run-off. When these losses are calculated over a crop area then they can become considerable. For example, nursery D would have lost 11.3 kg of N for every 10,000 plants grown. If a proprietary feed mix had been used (e.g. 15-5-15) then this would require 57 kg of fertiliser which is equivalent to three bags (20 kg). Where fertiliser costs £1.00/kg then there is a direct loss of £57.00 for every 10,000 plants grown. Nursery D actually produced about 200,000 Poinsettias. Had all these plants been grown on the same system then 1140 kg of N would have been lost with a cost of £1140. Clearly there are financial reasons why growers should consider minimising water and fertiliser losses. This is discussed further in Section 3.3.

Nurseries A, B and C participated in the Bulrush Poinsettia Monitoring Scheme. Appendix XVI shows the results of the leaf tissue analysis. Leaf nitrogen content remained relatively consistent between the three (nursery D did not send in the correct samples and is therefore not included in the leaf tissue analysis) participating nurseries.

Water Quality

Water quality was analysed as described in Section 3.1. Full results of analysis are shown in Appendix X to XIII. Figures 9 and 10 show the levels of nitrogen ((NO_3 ÷ 4.427) + (NH_4 ÷ 1.286)) present in the irrigation and run-off water at each test.

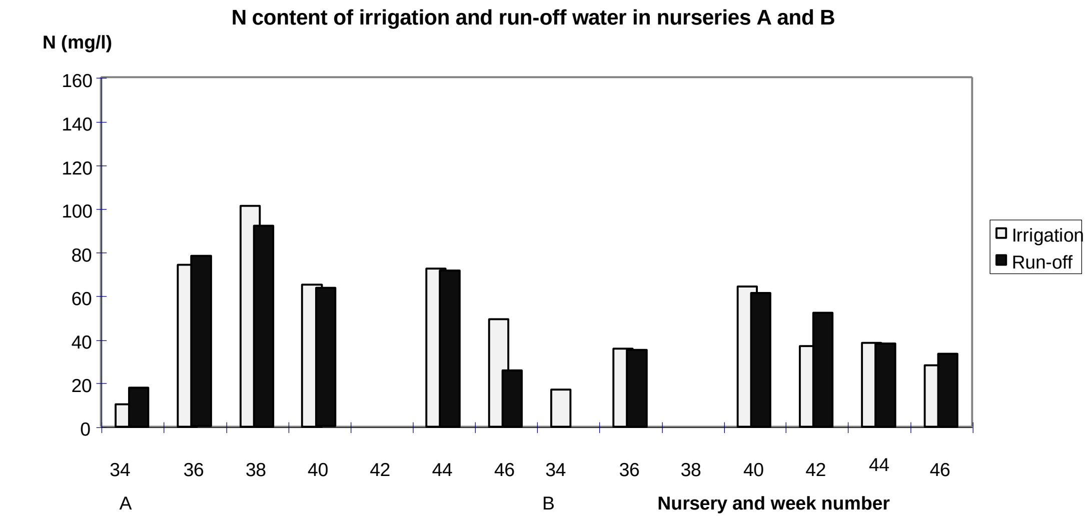


Figure 9 - Nitrogen content of irrigation and run-off water in nurseries A and B.

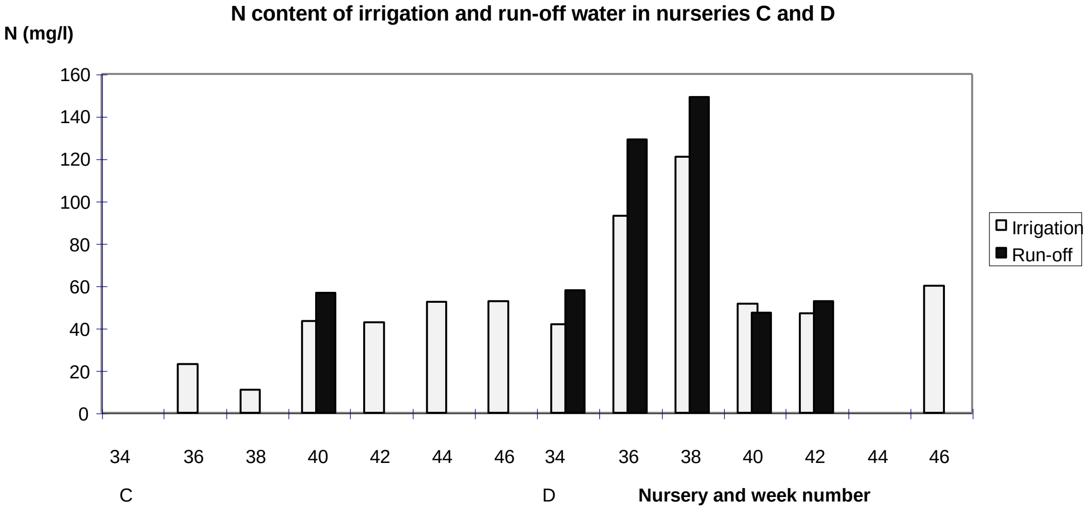


Figure 10 - Nitrogen content of irrigation and run-off water in nurseries C and D (Note that run-off samples were only collected from Nursery C in week 40).

These results show that the different nurseries have different approaches to liquid feeding. On systems where capillary matting is used, the N content of the run-off tends to be higher than the N content of the irrigation water. This is due to the fact that as nitrate is leached from pots it is held in the matting until the next irrigation when it is leached out as run-off. As water evaporates from matting it can leave the N behind leading to high N accumulations. Consultancy experience has shown that this high N can produce high conductivity levels (ECs) which can scorch roots. Nitrate is very prone to leaching. Levels of phosphorus (P) and potassium (K) in run-off were also high.

EC levels in the irrigation and run-off water are given in Appendices X to XIII and the levels are closely linked with nitrogen levels. The pH of water used varied between nurseries as well as between weeks on the different nurseries. The lowest pH's were observed on nursery A where irrigation water dropped below pH 5.0 on two occasions. The highest pH of 7.8 was observed on one occasion on nursery C. The mean pH on the tested nurseries is shown in Appendix XVII.

Growing Media

Growing media from each nursery were analysed for AFP and particle size at the start and end of the season. Appendix XVIII shows the results of these analyses. The results show that the different media, all of them blended for Poinsettias, were fairly consistent in AFP and particle size. This enables results between nurseries to be compared accurately.

The results given in Appendix XVIII show that most of the AFP's, on the nurseries tested, were in the 4-9% class, although nurseries A-D, showed an apparent improvement in the AFP's over the assessment period.

Plant Quality

The test plants were scored for quality to assess their marketability. Results from the quality scoring are shown in Appendix XIX. The quality results were compared with typical supermarket specifications. All the plants assessed were considered to be of marketable quality which was typical of Poinsettia crops grown across the UK. However, all nurseries failed to meet height specification (see Appendix XIX). Plants on all nurseries were shorter than the ideal. However, some supermarkets did lower the height specification to 25 cm during the 1999 season, probably due to difficulties in finding crops of sufficient height. The plants at nurseries A and C had two weeks following the assessment to put on more height before the peak selling period.

Supermarkets specify a minimum of five breaks. The plants analysed in this test had approximately four heads but had sufficient secondary heads to meet the specification. The Poinsettias assessed did not represent the highest quality but were typical of UK production.

3.3 Discussion

3.3.1 Stage 1 - System Tests to Evaluate the Variation in Water and Fertiliser Use Between and Within Different Growing Systems on Commercial Nurseries

The tests were designed to assess the variation in water and fertiliser efficiency between a range of different production systems used for the production of protected ornamentals. Single irrigation tests were carried out on each nursery. This irrigation was timed around the week 38 production week for Poinsettias. Therefore all the Stage 1 irrigation tests were carried out when the crops in all the participating nurseries were at a similar growth stage. There are clearly limitations to carrying out such a test as a 'one-off' on so many different nurseries and for this reason the results should not be taken as absolutes but rather as a general guide. Crops would not have been at exactly the same growth stage and the moisture content of the growing media at the start of each test, may have varied a little between nurseries. However, data presented in Figure 1 showed that there are clear trends in water loss between the different categories of systems tested.

These Stage 1 tests proved to give key support to those carried out in Stage 2. In Stage 2, four nurseries were monitored through the whole production season for water use and loss. The Stage 1 results helped to demonstrate the variability both within and between production systems and in one case to highlight that the Stage 2 test for hand-watering (Nursery D and Hand B are the same system) was not necessarily typical of other hand-watering systems.

Each category of systems are considered below to assess their efficiency and potential for water saving:

Ebb and Flow

The main advantage of these systems is that the volume of water or fertiliser applied is not critical because the solution that is not used by the crop during an irrigation is recirculated to be available to other plants. The only losses that may arise would be from leaking benches or from emptying the recirculation tank. Tanks are emptied once or more through the season but very often the tank levels are allowed to run down first to minimise the quantity for disposal. In any case the quantity lost is likely to be considerably less than losses from open systems.

This system has been identified as the best for legislation compliance in countries such as Germany and The Netherlands. The practical advantages and disadvantages of the systems are described in greater detail in Section 2.2. The main reason why the system has not been adopted to any great extent in the UK is the capital investment cost in setting it up. These costs are given in Section 4.2 and show a typical cost of £33/m^2 for an ebb and flow recirculating bench system.

The systems of greater concern are those ebb and flow flood systems that do not recirculate and just run-to-waste. In these cases, losses of water and fertiliser will be very high and if the data in Figure 2 is used as an example, then losses could be between 40 and 120 litres of water per plant per season. This level of loss is very high but not widely different from losses from Cap B2 and Trough A systems.

Capillary systems

Many irrigation systems for protected ornamentals rely to some degree on various types of capillary matting. The results from tests on capillary systems show wide variations, for example between Cap A1 and Cap B2. However, it is interesting to notice that the layout and construction of these two systems is largely the same with trickle tapes overlaying 'Mypex' or polythene overlaying capillary matting. The difference is in the management of the system. The grower in nursery Cap A1 irrigates 'little and often' whereas the grower in Cap B2 treats the system as an open form of flood flooring. In Cap A1 the irrigation is on for approximately nine minutes and in Cap B2 the irrigation is on for over an hour. This simply highlights that, if nursery Cap B2 had followed the practice of nursery A1, approximately 500 ml of water per plant could be saved at every irrigation. This saving would not only be in water but also in liquid feed, which is incorporated in most, if not every, irrigation.

The quality of the capillary matting used will influence its effectiveness. Old or poor quality matting tends to be of little benefit and will not store or distribute water very well. Good quality matting, on a level surface, can distribute small quantities of water well but is not able to absorb very large volumes, such as those applied in Cap B2. There is good potential for developing capillary matting systems for greatly reducing water losses without excessive expense. Growers should aim to adopt a system that makes full use of the matting properties and applies water evenly to the matting. It is proposed that different mattings and their properties are evaluated in a future study. Growers who rely on matting for irrigation must also be confident that the floor surface is level. Any undulation can lead to poor uniformity of water supply and for this reason many growers use matting as a buffer rather than as the sole irrigation method.

Trickle/drip systems

These systems, with drippers placed into each individual pot, are extremely efficient, with a loss as low as 20 ml per plant at each irrigation, compared with a loss of 54 ml per plant in the most efficient capillary system (Cap E). The only potential area for water loss is if the dripper has been pushed down to the pot base (so water drains straight out of the bottom) or if the media water holding capacity has been reached. Losses can also occur if not all the drippers are placed in the pots but on the whole water loss is very low. The results in Tric A1 showed some inefficiency and this was found to be due to some drippers being at the base of the pot, which was then corrected. When the test was repeated the average water loss from each plant at each irrigation was reduced from 95 to 20 ml. The other advantage of drip systems is that they optimise chemical and fertiliser use.

The main disadvantage with trickle irrigation is the initial cost and labour requirements to insert the drippers. The system is not suitable if growers need to space the crops a number of times unless long drip leads are used. Nursery Tric C set up their drip system with plants at a very wide spacing (4/m^2 compared to the typical 10/m^2) from the start of production, then installed the drips and did not space them again. This is practical where the space is available but most nurseries need to space plants to maximise the use of available area. Drip systems used with water high in bicarbonates are liable to furring up with calcium deposits and acid dosing should be incorporated in the irrigation system.

Trough track

Water loss levels in this system are very similar to those for recirculation in the ebb and flow systems. This system showed that almost 1.5 litres of the water applied to each plant at each irrigation was lost and drained off the end of the troughs into the ground. Trough track offers the potential for efficient water use but only when it is a part of a recirculating system. The cost of the water lost by the nursery using this system was not significant as water was taken from a borehole. However, such systems are very wasteful particularly as fertiliser is incorporated in all the lost water.

Hand-watering

These nurseries water using a hosepipe. This method is labour-intensive and potentially very wasteful, with losses up to 613 ml per plant in one irrigation (Figure 1). Hand-watering with a lance on Poinsettias can also damage the plants if not done with care. Nursery Hand B is the same as Nursery D in Stage 2; the reasons for the different results from this nursery are explained later in this section.

Spraylines

Spraylines are not widely used for Poinsettia production and therefore the test for this system was specifically set up for the project. It was considered that spraylines should be tested as they represent a significant number of the irrigation systems used under protection particularly for bedding crops. The sprayline system wasted 159 ml water per plant. This inefficiency was not surprising but it is interesting to note that losses were not very different from most of the capillary systems.

Water Quality

The importance of good water quality is described later in this section. Nitrogen (N) levels are a good indication of nutrient levels in the water. These were shown in Table 3. It is interesting to notice that some nurseries start off with water containing N, e.g. nursery Ebb C had 12.2 mg/l N in the water used from the borehole. Once feed is added this makes N levels in the irrigation water very high. It is wise for growers to regularly analyse the water used as such high levels of nutrients in untreated water should be accounted for when adding feed. The high levels of N in run-off water highlights how easily N is leached from containers. In some cases the N level in the run-off was higher than the level applied in the irrigation water. This tends to occur where capillary matting is used. Water (including feed) is stored in matting but some of the water will be evaporated from the matting during hot weather, leaving a concentration of N in the matting. This has become a problem on some nurseries where EC levels of the matting have reached such high levels that crop roots have been scorched.

Growers should be aware that run-off water contains as many, if not more, nutrients than the feed mix applied to the crop. In most cases the run-off exceeds the 11.3 mg/l N limit set by the EC Drinking Water Directive. Growers found to be allowing this run-off, at this N concentration, to enter watercourses could face legal action if discovered.

3.3.2 Stage 2 - Measurement of the Efficiency of Water and Fertiliser Use in Different Production Systems for Poinsettia throughout the Duration of the Crop

Total water application

Figure 5 shows the water application trend for each nursery in Stage 2. More detail is shown on the graphs in Appendix VIII. The highest water applications to the crops were, not surprisingly, in nurseries A and B. Both these systems are recirculating and based on flooding. Nursery B uses capillary matting, in addition to the flooding to prolong retention, and this is reflected by the lower volumes of water applied. The systems tested in nurseries C and D are not recirculating and therefore water not used by the crop is lost. N.B. not all 'lost' water is run-off. Some will be evaporated and some will be held in the matting for a while before taken up by the crop.

The charts in Appendix VIII show the different watering strategies adopted by each nursery. The ebb and flow flood bench system in nursery A applied set quantities of water at each irrigation. This was adjusted once as the season progressed, by increasing the length of flooding time. The earliest part of the season represents a period when the crop was hand watered. Although nursery B also floods based on a set number of minutes, the actual quantities applied varied between irrigations. This may have been due to variations in water pressure, as the water meter installed on the system accurately recorded water application. Irrigation was applied fairly consistently during September and the early part of October and after this smaller amounts were applied due to prevailing weather conditions. Appendix IX shows that light levels in nursery B were lower from the second week in October, so reducing evapotranspiration and crop demand for water.

Nursery C applied a 'little and often' approach through the season until the second week in October, when application increased significantly. This coincided with high light levels as shown in Appendix IX, and followed a period when water had not been applied. The most likely explanation is that the plants were dry and needed extra water to return compost moisture to the correct level. Water was not applied during the last part of October and again this coincided with a period of low light levels and cooler weather. The increase in water application in November also reflected weather conditions in addition to the growth stage of the crop nearing sale.

Water application in nursery D adopted the 'little and often' principle to a greater degree. For much of the season the crop was watered nearly every day, although in many cases this was spot treatments of dry areas. The higher water applications in early October coincided with high light levels as well as following a period when the crop had not been watered. There was some concern that the quantities of water applied in the system seemed remarkably low compared to the results from other hand-watering systems as described earlier. On further investigation, it was found that although the crop is hand watered, the water applied to the bench did not really drain from the bench but was trapped by the polythene overlaying the benches. The polythene was curled up at the sides of the benches and acted almost as a flood bench. Plants take up virtually all the water applied as they sit on the bench. Without careful monitoring of crop condition, this system could be risky in terms of crop quality, as overwatering could very easily occur. For this reason, this system may not be typical of hand-watering systems where unused water drains as run-off. This result highlights the value of the Stage 1 tests, the data from which can be used to assess typical water losses from hand-watering systems.

Water Uptake by the Crop

The quantity of water taken up by a plant in a container at any one irrigation will depend on a number of factors. These include:

- Quantity of water reaching the pot.
- Initial moisture level (saturation) of the growing media.
- Water holding capacity of the media.

The degree of wetness in the container before and after irrigation depends largely on the watering ethos of the nursery. Some nurseries are notably ‘wet’ whereas others are ‘dry’. The ethos adopted will depend on what the individual grower feels is best for the crop, labour requirement for each irrigation and the overall cost of each irrigation operation. In some ways it would have been useful to ensure that irrigation only took place when the crops on all the nurseries in this study reached a set level of dryness. This could have been measured by use of soil moisture probes similar to those discussed in Section 2.1. However, in reality it would have been unrealistic for participating nurseries to irrigate based solely on soil moisture measurements without past experience with the technique. In addition, use of soil moisture probes would not have been an accurate reflection of actual commercial practice.

Figure 6 showed the variation in mean water uptake in each of the different nurseries along with error bars to show the range in different irrigation tests. The lowest levels of water uptake were in nursery B and the highest in nursery D. The uptakes for each nursery can be explained by the irrigation system and approach used.

The lowest uptake on nursery B can be explained by the reliance on capillary matting in this system. Matting is flooded at each irrigation and the plants take up water over the following hours. The tested plants were weighed approximately 30 minutes after each irrigation but by this time the crop may not have taken up all the water available from the capillary matting. If the plants had been weighed a few hours later, the weights may have been greater. However, after additional time other factors would affect water volume, such as evapotranspiration which would reduce the water volume in the container. Thirty minutes after irrigation was an acceptable compromise but this may explain why uptake seemed lowest in this system.

Uptake in nursery A was slightly higher and this was probably due to the higher flooding levels and the fact that the system does not rely on capillary matting. The uptake levels were not as high as nurseries C and D as nursery A tended to keep plants in a wetter condition and irrigated more frequently.

The highest uptake was observed in nursery D. This is to be expected as the water applied remains on the bench surface until it is taken up by the crop. The plants were drier before irrigation than other nurseries due to the use of high heating temperatures under the bench. Nursery C was intermediate between nurseries B and D as the system is a combination of capillary and flooding which holds water on the benches for shorter periods.

Analysis of variance was used to compare weights before and after irrigation and any differences between the seven irrigation tests. This analysis showed that there was nearly always a significant difference between the different nursery sites in terms of plant weights before and after irrigation (see Figure 6). The weights of tests plants were more variable in nurseries A and D in the first two tests than later in the season. This is simply explained by the fact that both nurseries relied on hand watering for this test phase. Therefore saturation levels between pots would have been variable until plants had established in time for the later tests.

The final analysis combined the data for each site and showed that the differences between sites were consistent over time. Nursery C usually had the lowest weights after irrigation and the smallest difference in weights. The biggest weight differences were seen on Nursery D, where hand-watering was used, as discussed above.

The mean water uptake data for each nursery were used to calculate the total water uptake through the season as shown in Figure 7. Total water uptake varied between nurseries:

- The highest water uptake seemed to be in nursery A where each plant took up approximately 10 litres of water through the season.
- Water uptake was nearer to 4 litres in nurseries B and C but as stated above it should be remembered that these systems rely on capillary matting and water uptake may extend beyond the period after the final weighing.
- Nurseries A and D represent systems where water uptake is fast and therefore it has been possible to record the full uptake values.
- A margin of error (of a few litres per plant) should be accepted for nurseries B and C. However, this does not change the overall trends shown by the results when calculating water losses.

Water Loss

Other than losses from leaking benches, the occasional emptying of water tanks and evaporation, there are no losses from the flooding systems in nurseries A and B. Unused water is recirculated and the advantages and disadvantages of the systems were described earlier. The water losses from nursery D seem remarkably low compared to the hand-watering systems. The Stage 1 results clearly highlighted that this system was not typical of hand-watering systems. Nursery D is an interesting example of how systems that are relatively cheap to set up can be efficient in water use.

The watering system tested in nursery D is described in Section 3.1. It was not easy for the water to run-off from the bench and most is kept on the bench. Thus the system is a ‘semi-flooding’ system which clearly uses water very efficiently. With careful management, Poinsettias can be successfully grown under this system. Section 3.2 shows that the crop was of marketable quality. However, there are drawbacks. The crop would need to be managed very carefully; this nursery had one individual responsible for the irrigation, who did not over-water the crop. When water is trapped on a bench, in this way, there is a danger that the media could become saturated and promote disease spread. This particular crop did not suffer from these problems; it was carefully managed and also the benches were heated, so excess water would soon have been evaporated. Another drawback is the labour requirement in a system like this. Section 4.2 shows that labour costs for glasshouse hand-watering can be £4,680 per year. These needs to be compared with the costs of installing a mechanised closed system.

The cost of water loss is referred to in Section 4.1. Water costs would be highest in nursery A if mains water was used with a cost of 4 pence per plant. This would cost £400 to irrigate 10,000 plants for a season. However, water costs are not high when considered in this way. The cost of fertiliser is more significant.

Fertiliser Application and Loss

Quantities of fertiliser used and lost from each system are shown in detail in Appendix XV. The quantity of fertiliser applied and taken up are based on the quantities of water applied and taken up. N is a good indicator and the element of most concern from the point of view of run-off. Figure 8 shows that the actual plant uptake of N in the different systems varies from 0.54 g per plant at nursery C to 0.91 g per plant at nursery B. However, compared to the figures for unused N, these figures are quite consistent between nurseries. The highest loss of N was at nursery D where for every plant 1 g of N was lost through the season. The example given in Section 3.2 showed that this could be equivalent to 11.3 Kg of N per 10,000 plants grown.

If a number of assumptions are made this information can be used to estimate fertiliser losses from the systems in Stage 1 tests. The assumptions are as follows:

- 10,000 plants are grown
- Grower uses a proprietary feed mix containing an NPK ratio of 15:5:15
- Stock solution is 1 kg fertiliser in 10 litres water
- Stock solution is diluted to 1 in 100 giving 1 kg of fertiliser in 1,000 litres of irrigation water and 1.0 g of N in 1 litre of irrigation water
- Fertiliser costs £1.00 per kg
- Feed is applied in every watering
- Water uptake on each system is 6 litres per plant
- N levels in run-off are the same as in the water applied (Appendix V shows this is a fair assumption)

The estimated fertiliser losses are shown in Figure 11.

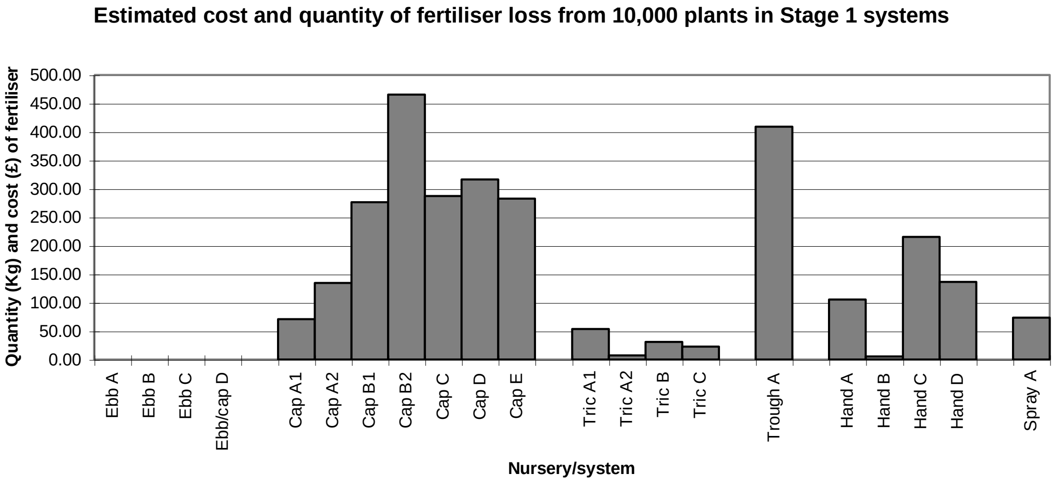


Figure 11 - Estimated cost and quantity of fertiliser loss from 10,000 plants grown in Stage 1 systems through the production season.

Clearly many of these assumptions will not apply to all nurseries but the figure shows an example of the losses of fertiliser and the value of those losses. It is alarming to calculate that Nursery Cap B2, if it was growing 100,000 Poinsettias on this system, could be losing 4.6 tonnes of fertiliser with a value of £4,650. With Poinsettias spaced at $10/m^2$ then this is equivalent to £4,650 / ha.

Data such as this helps to highlight the potential inefficiencies of some production systems. However, the data also shows how systems that are not necessarily 'closed', can be made to be efficient. For example the losses from nursery Cap A1 were only 15% of the losses from Cap B2. These two systems are similar but the different approach to watering gives this huge variation in results.

Appendix XV also shows that losses of K and P were high and in some cases losses of K were considerably higher than N losses. Fertiliser can be saved by applying different mixes (according to crop requirements) through the season but the greatest savings will be obtained by improving application efficiency.

Growing Media

All the samples had more than 20% <2mm particles and it can be argued that this high proportion would certainly reduce the AFP values. However, the materials selected for the 1999 growing season will nearly all have come from the 1998 peat harvest which was, for all suppliers in Europe and the Baltic, very poor quality. The harvest conditions and the peat in store were wet. This led to very fragile structures of peat being produced which, when dried, easily broke down.

The dry sieving method used in the assessments was originally developed for soils, and relies on the aggregates remaining stable at the various particle sizes in order to give a true picture of the particle size distribution. In this case the drying of the peats, which were already fragile in their wet state, probably inflated the percentage of particles less than 2mm. Arguably this would occur anyway as the material is screened, bagged, tipped, put through potting machines and watered. Even where attempts are made to reduce the <2mm particle content of the materials in a bad year they cannot be realistically removed. Additionally, where additives such as bark and perlite are added they are not pre-screened to remove excess levels of <2mm and they can even lead to a greater overall percentage of this fraction.

The most important message from this data is that these type of determinations should be made more regularly with substrates. This will allow the management strategy on the nursery to be adjusted to optimise the nature of the substrate. In years where the substrates, from whichever source, do contain 20-30% <2mm particles and the AFP's are low, then the water management has to be very careful to avoid excess wetness, particularly in the base of pots.

The Importance of Water Quality

Potable Water Supplies

Many nurseries in the UK use mains water as it is regarded as being of the highest quality. Certainly any public mains supply in the UK is of the highest quality with regard to its 'potable nature', i.e. the indication that it is fit for human consumption. Water companies must meet standards for the potable water supplied. However, whilst the water in the mains may be fit for drinking, its fitness for use on ornamental crops may be significantly different. For example, the human detection point for chloride in water is 250 ppm and the upper threshold for action by water companies is 450 ppm chloride, but it is recognised in horticulture that levels of chloride above 80 ppm may cause severe restriction in plant growth.

Rainwater

The purest natural water is rainwater before it reaches the ground, assuming that there are low levels of atmospheric contaminants such as sulphur dioxide and nitrous oxide. Even if these two oxides are present the rainwater will still be relatively 'clean' in chemical terms. Once the water touches a surface then the nature and properties of that surface will determine the subsequent quality of the water.

If the rainfall falls on hard impervious rocks, such as those in the Scottish highlands and English Lake District, then the water collected in the surface reservoirs will be devoid of many additional minerals with the exception of aluminium and silica. The exception to the rule is where the slightly acidic rainwater in these areas first passes through the upper organic 'peaty' soil layers, absorbing organic complexes (fulvic and humic acids) and then passes through heavy metal veins such as those consisting of zinc, copper and arsenic.

This can result in an organic complex of such mineral deposits which can eventually reach reservoirs. This problem was recognised in the very early days of mains water supplied from such areas. Methods of 'flocculation' of the organic colloids have become established practice to both clarify the water and remove the metals.

The resultant mains water from such sources has little or no dissolved carbonates other than those applied at the treatment works to avoid corrosive action on metal pipes in the system. This was introduced once it was realised that soft slightly acidic water was continuously dissolving lead supply pipes and hence giving human health problems. This type of water, if supplied in public mains, is the purest and softest water and is the easiest to deal with for both fertiliser inputs and effectiveness for avoidance of problems such as algal growth.

At the other extreme of the spectrum is the rainwater which initially falls on chalky soils overlying chalk rock. In this case the slight acidity of the rainwater starts the process of dissolving carbonated minerals in the profile, to the extent that the water entering a chalk aquifer is saturated, both in elements such as calcium and magnesium and also carbonates in the form of bicarbonates, which give rise to temporary hardness of the water. Water on the south coast and the London basin, where the boreholes for public supplies are direct into the chalk aquifers, can carry the maximum possible levels of temporary hardness. This is usually expressed as the alkalinity of water and can be 350 ppm or more. This water is in reality a saturated limewash solution and will cause rapid increases in the pH of substrates over a few weeks of use. The smaller the container, the faster the rise in pH. This rise in pH will then have the associated problems of nutrients being increasingly limited in their availability to the plant. There will also be a greater tendency for algal growth and deposits both on leaves and from drippers and overhead spray nozzles.

In between the extremes of the very soft and the extremely hard waters there are many variations. In addition, local geology may influence the water quality in other ways. For example, water taken in areas around the Winsford area of Cheshire, the Newport area of Shropshire, the Droitwich area of Worcestershire, or the Windsor area of Berkshire may come from boreholes that have very high levels of sodium chlorides. This is because each of these areas sits over naturally occurring deposits of rock salts. Similarly, water in parts of Nottinghamshire taken from marine coal bands may also have high chloride and sulphate levels. Additionally, in some coastal areas the saline head of water may have exceeded the fresh water head so much that boreholes have in fact turned saline. Examples of this are to be found in the Pilling area of Lancashire and the Essex coastal areas.

Chlorides

Chlorides, as a hazard in water supplies, have long been recognised in some sectors of agriculture. An ADAS report on water quality in the eastern region (Anon, 1970) for the dairy industry considered the water in terms of the chemical quality of farm water supplies on a parish by parish basis. Many of the samples indicated extraordinarily high levels of chloride. Ranges from 30 ppm, which is a typical background level, to 1200 ppm were found. Even within some specific parishes, different sampled boreholes gave readings which were at least a factor of two to three times different.

Nitrates

In more recent times, from the early 1980's onwards, considerable attention has been paid to nitrate levels in drinking water and the association of high nitrate levels with 'Blue Baby syndrome' (Briercliffe, 1998. HDC PC 59a). At present the World Health Organisation (WHO) recommendations for water fit for drinking to restrict the nitrate content to 50 ppm nitrate or 11.1 ppm N. Studies in this project, around the UK indicate that background levels of nitrate N can be far in excess of WHO recommendations. In some cases nitrate N can reach levels at which the ‘raw’ water for many crops is in fact a dilute feed.

Iron

Finally, the iron content of many borehole waters may give rise to problems both in terms of precipitation, in the form of orange ochrous slimes and also the deposit on leaves of a film of oxides. Many boreholes carry iron in a reduced state, such that it is mobile. However, on exposure to air the oxygen rapidly converts the reduced iron to an oxide which then causes the problems described. In the USA, systems exist for the removal of the iron after oxidation with strong oxidising agents such as permanganese. This is currently being investigated in the UK for commercial development.

3.4 Options for Improving Efficiency

3.4.1 Improving Existing Systems

Growers wanting to completely eliminate run-off will have to look seriously at recirculating closed production systems as specified and costed in Section 4.2. Comments on the viability of installing new systems are discussed in Section 3.4 below. However, many growers will not wish to invest in new production systems. After all the factors are taken into consideration it may be more realistic to maintain existing systems but improve the efficiency. Section 8 of HDC project PC 59a (Briercliffe, 1998) outlines some key options for minimising run-off. In addition to the suggestions below, this also suggests paying careful attention to media selection. This will involve a compromise; on the one hand growers want an open media but on the other such media can promote nutrient leaching. Wetting agents can be incorporated (as they are in most proprietary media mixes) to alleviate some water losses. This section considers how efficiency can be improved in each of the systems tested in this research.

Ebb and flow and trough track systems

Little can be done to improve the efficiency of these systems if they are recirculating already. The main concern is to ensure that these systems are recirculating. Trough A system is an example of such a system that does not recirculate and there are some growers using ebb and flow benches that run-to-waste. In these cases the volumes of water, that are recirculated, will be lost as run-off (see Figure 7).

Water losses can occur in a recirculating system, particularly when the recirculating tank is emptied. Good practice for these occasions would be to let the tank run as low as possible before emptying it. Water can also be lost by evaporation directly from the bench or floor, particularly if the flooding process lasts a long time. Research by Otten *et al.* (1999) cited in Section 2 showed that most water applied to flood benches is absorbed within the first five minutes and therefore frequent applications of small quantities will result in more efficient water use. The increased frequency of irrigation on these systems rarely results in increased labour, as such systems are largely mechanised already.

Capillary systems

The wide range in water losses from capillary systems was shown in Figure 1. The key method for improving efficiency in these systems is to adopt a 'little and often approach'. Efficient capillary systems will have the following characteristics:

- Good quality capillary matting which has not deteriorated with overuse.
- Matting placed onto a level surface.
- Matting should have a solid film underneath (e.g. polythene) to prevent leaching through to the ground beneath.
- Matting can be overlaid with perforated polythene to increase its lifespan and reduce moss and liverwort contamination.
- Water can be applied by drip/trickle tapes or emitters but water release on the matting should be balanced across the mat area to avoid concentrated pockets.
- Water should be applied 'little and often' enough to wet the matting without producing run-off; where beds are not level then more water will need to be applied. The length of time recommended for each nursery will vary depending on matting, system and water pressure.

There are a number of capillary matting products available to growers but there is little independent data to show which are the best to use. *Further work is needed to assess the different options available to growers and for developing the most efficient capillary system. In the mean time growers should experiment with different high quality mattings as quality varies considerably.*

Drip systems

The research showed that drip systems were very efficient and they only cost another 70 pence/m^2 to install compared with a capillary system (see Section 4.2). The main drawback is the labour required in inserting and maintaining drip nozzles. The system works well on pots that are large enough (i.e. 1 litre or above) but are not practical for smaller pots or packs and trays. Even with drips in large enough pots there can be problems when it comes to spacing and crop handling. Drippers need regular checking to ensure they are emitting water in the right place and are not blocked. The nurseries tested in Stage 1 tests, that use a drip system, find it very effective and they would not change to a different system. The dry aerial environment also helps to prevent disease spread.

Hand-watering

These systems are notoriously inefficient and labour intensive. Although they are the cheapest systems to install they are the most expensive to run (see Section 4.2) and with the problems of crop damage, poor uniformity and a shortage of horticultural labour, many growers are turning to alternative options.

The efficiency of any hand-watering system depends largely on the individuals who do the job and how well they are aware of crop demand and when they reach the point that they are applying too much. The nature of the Poinsettia crop means that, to avoid foliage damage, any watering lance has to be directed to the pot underneath the foliage and hence much of what is applied is lost onto the floor. The use of polythene and capillary matting under the crop will help to retain some of the water lost and growing crops on benches will give greater control and reduce potential physical damage.

Nursery D is an example of an efficient hand-watering system but, as with most efficient systems, it also relies on capillary action to some degree. Simply using a shut-off valve on the lance is another way to ensure water is not wasted when the crop is not directly being watered.

Spraylines

Work by Hall *et al.* (1998) showed that overhead sprinklers lost between 55 and 79% of the water applied. This agrees with the results in this project, which showed that the sprayline system evaluated was on the more efficient side of these values. The sprayline system tested was attached to a boom and was therefore probably more efficient than many attached to roof lines. These systems are heavily relied on for the production of protected ornamentals but are only about 50 pence/m^2 cheaper to install than a capillary system. The overhead spray is not only inaccurate and wasteful but also promotes an environment suitable for the spread of disease pathogens and algae.

The efficiency of these systems can be improved to some extent by improving the layout of nozzles and choosing the best type of nozzles. The system should be designed so that the spray irrigates the beds containing crops rather than the paths. Irrigation should be applied during dull periods when high temperatures will not lead to high evaporation rates. Nozzles at the ends of rows should have 180^o angles. Beyond these simple steps there is little potential for water saving in these systems under protection.

Gantry systems

These systems provide a more targeted water application and in production of packs of plants these can be very efficient. Water is not lost to paths and carefully targeted nozzles ensure good uniformity of water application. Efficiency can be improved by shutting off nozzles in sections where plants are not present and applying water during dull periods to minimise evaporation. As with spraylines, gantry systems are not used to any extent in the UK for the production of Poinsettias and therefore could not be included in directly comparative work.

Minimising fertiliser losses

The research in this project has shown that fertiliser losses can be very high. Most nurseries feed Poinsettia crops at virtually every watering. It is better to do this than apply large quantities all at once but application should still be based on an understanding of both crop requirements and the nutrient status of the growing media. Media should be regularly analysed and fertiliser application should be adjusted to meet the requirements of the crop as the National Poinsettia Monitoring Scheme aims to do. This practice could potentially save considerable quantities of fertiliser as well as improving crop quality.

3.4.2 Investing in new systems

Few UK nurseries are investing in fully recirculating systems. Primarily this is due to the high cost of ebb and flow flood systems (£28.60-£33.29/m^2) in the initial installation. However, when considering such systems a long term view needs to be taken and all aspects considered. Horticulture is facing a crisis in terms of labour shortages. The systems that are cheapest to install are also those with the highest labour requirement. The annual labour costs for a hand-watering system in Section 4.2 were estimated at £4,680 compared with £1,196 in an ebb and flow floor system. This may still mean a long-term pay back, but as pressures on labour and water increase so these should be considered as serious options.

The irrigation system frequently takes a position of low priority in nursery planning but any new developments on a nursery should carefully consider this aspect. However, ebb and flow flood systems are not the only option recommended here. Manufacturers are increasing the number of products on the market available to growers. One example is the 'Bottom-Up' system from Australia (supplied by LBS Horticulture). This system consists of a sealed matting with pipes feeding water onto the matting. The principle behind it is the same as ebb and flow systems but the cost is lower. The suppliers claim a minimum water saving of 60% compared to overhead systems but as with most capillary systems it is important to have a level surface. The cost for these systems varies depending on the width purchased but an example is the 1.5 m width which costs £25.24 for the first metre (including cost of a pressure regulator) and then £6.60 for each extra metre (summer 2000 prices). This still makes the system fairly expensive compared to other capillary systems which can cost £2-3/m^2 to install.

Growers installing new systems should take care to ensure that the aspects discussed in Section 3.4.1 are taken on board.

3.4.3 Collecting and Recirculating Irrigation Water

The collection and re-use of run-off water is an obvious way of reducing water losses and increasing the efficiency of water use. However, in practice this can require extensive construction work. Systems, such as ebb and flow are often designed to collect and recirculate run-off water but most other systems are not designed with this in mind. The feasibility of setting up such a system will vary from nursery to nursery. Some can make use of natural slopes or previously installed drainage systems, whereas others will require more work.

Once space has been found for storing collected water the next main problem is how to overcome the threat of disease. Run-off water will often have been in contact with plant material as well as moving across the ground and other surfaces. These all contribute to the likelihood of picking up disease pathogens in the water. The different options for preventing disease spread and the treatment methods available are outlined in Section 4.3. The costs listed in that section need to be weighed up against the costs of installing more efficient irrigation systems or simply modifying existing practice to improve efficiency as described in Section 3.4.1.

Reed beds provide another alternative for water treatment. Reed bed systems work on the principle of an artificial wetland. They rely on the flow of water through gravel or soil in which reeds are growing. The key features are as follows (Lightfoot-Brown, 1999):

- The rhizomes of the plants open up the substrate to provide a hydraulic pathway
- The waste water is 'cleaned' through aerobic and anaerobic bacterial activity which breaks down chemical residues and removes pathogens
- The chemical load of the water is further reduced through uptake of minerals by the root systems

The most commonly used plants in such systems include *Phragmites australis*, *Typha latifolia*, *Iris pseudoacorus* and *Scirpus lacustris*. Various reed bed designs can be adopted to collect nursery run-off and feed it through the reed beds. One of the key drawbacks with this system is the large area that the beds occupy. The larger beds are the most effective and nurseries need to have considerable space for setting up such systems. Reed beds are known to be effective at removing suspended solids, nitrogen, phosphorus and heavy metals but they are relatively unproven in respect of plant pathogen removal. As with slow sand filtration a reed bed develops a microbial ecosystem which is likely to be antagonistic to plant pathogens but further work is required to assess how effective and reliable this is.

4. WATER, IRRIGATION AND WATER TREATMENT COSTINGS

4.1 Water Costs

UK growers use water from the following main sources: boreholes, wells, surface water abstraction, rain water collection, recycling and the mains. Water abstraction from boreholes, wells and surface waters requires a licence which can be obtained from the Environment Agency and once the system is operating the water costs are relatively low. However, many growers still rely on mains water supplies, which incurs a significant production cost. The cost of water varies throughout the UK. Some examples of this range in prices are shown in Table 4.

Table 4 - Water Company prices paid by nurseries in 1998 (Anon, 1998).

Water Company	**Price paid £ per m^3**
Mid-Kent	0.68
Three Valleys	0.58
Cambridge Water	0.57
Yorkshire Water	0.75
Anglian Water	0.68
Severn Trent	0.65-0.74
South West Water	0.81
South East Water	1.00
Southern Water	0.58-0.60
North Surrey Water	0.62
West Hampshire Water	0.56
Thames Water	0.60
Portsmouth Water	0.41

Some more recent figures showing water prices in different UK regions in 2000 are shown in Table 5.

Table 5 - Water Company prices paid by nurseries in 2000 (Source: Bulrush Peat Company Ltd.)

Region	**Price paid £ per m^3**
Stratford	0.76
Essex	0.62
Cambridgeshire	0.64
Kent	0.75
West Sussex	0.44-0.65
East Sussex	1.14
Cheshire	0.62
Lanarkshire	0.46
Inverness	0.68

European growers are less reliant on mains supplies for their water. Examples of the costings in some European countries are shown in Table 6.

Table 6 - Water costs for European growers (Molitor, Van Oost, Van Tol, pers. comm.)

Country	Cost of mains water (£/m^3)	Sources used on nurseries
Germany	1.25 - 1.57	Mains or borehole water which can cost (£0.13/m^3)
The Netherlands	Mains: 0.55 - 0.82 Bassin:0.27 - 0.55	Protected crops growers mainly use bassin and recirculated water. Outdoor producers tend to use recycled or dyke water which is free apart from the taxes paid towards dyke maintenance.
Belgium	Mains: 0.48 Wells: free but taxed at 0.03	Most nurseries extract from groundwater.

4.2 Irrigation Systems Costings

Any system adopted by growers must be financially viable to install and maintain. Water efficiency benefits have to be weighed up against financial implications. In this report, costing estimates for ten different systems for protected ornamentals have been produced. Systems vary immensely between nurseries and in order to make this excercise comparable a number of assumptions have been made:

1. All systems are supplied by the water mains into a galvanised water tank direct to the glasshouse.
2. Water is costed at 0.61 pence per m^3.
3. Any filtration of the mains water occurs before entering the glasshouse, unless specified for the system.
4. Any acidification of the mains water occurs before entering the glasshouse, unless specified for the system.
5. Adequate pressure is available to drive all systems.
6. All systems are fitted into a 1 acre (4047 m^2) 6.4m Venlo glasshouse. A total of 12 bays, 52m long with a central path running the length of the glasshouse.
7. Construction labour charged at £225 per man day.
8. Watering labour charged at £52 per man day.
9. The costs are based on summer 2000 list prices.
10. Glasshouses are used for 40 out of the 52 weeks of the year.

A summary of the costings is shown in Table 7. **Full details of the costings are shown in Appendix XX and Table 7 should be read in conjunction with this.**

Table 7 - Summary of system costings based on above assumptions

System	Set up cost per m^2 (£)	Annual running cost (£/m^2)
Ebb & Flow Floor (Recirculated)	28.60	0.51
Ebb & Flow Floor (To waste)	27.80	1.12
Ebb & Flow Benches (Recirculated)	33.29	0.48
Ebb & Flow Benches (To waste)	32.39	1.00
Gantry	23.18	0.67
Overhead	1.71	1.01
Hand-watering	0.46	1.38
Capillary Matting	2.24	1.02
Drip	2.92	0.39
Trough Track	26.63	0.83

N.B. costs will vary considerably depending on the type of glasshouse, crop grown and utilisation. When considering installing a new irrigation system, an irrigation consultant or company should be consulted to plan specific needs accurately.

The costings were calculated for each system following consultation with nurseries using each system, manufacturers and suppliers. It was assumed that standard fittings and equipment were used in each case and summer 2000 list prices were used.

4.3 Water Treatment for Preventing Disease Spread - Methods and Costings

Contaminated water can be a major source of plant infection, especially by phycomycete pathogens such as *Pythium* and *Phytophthora* spp.. It is therefore important to maintain good hygiene in water supply systems whatever the water source used. Whenever practicable, maintenance of plant quality by excluding plant pathogen propagules from production systems, (i.e. 'prevention rather than cure') is the best course of action. Water sources with a high risk of contamination with pathogen spores are those derived from surface water such as rivers. However, water from greenhouse roofs and even bore-holes can contain infective pathogen propagules. Perhaps the greatest risk of contamination with plant pathogens comes from collecting and recycling irrigation water. Research funded by MAFF at HRI on disease spread in production systems recirculating used water, demonstrated that:

- Disease spread was rapid when inoculated plants were introduced to recirculating systems in a broad range of plant species and production systems (i.e. pot plants in ebb/flood systems, containerised HNS on gravel beds, rockwool and NFT tomatoes and cucumbers and cut flowers in aeroponics, NFT and sand bed systems. Disease organisms shown to spread rapidly in such systems included, *Phytophthora, Pythium, Thielaviopsis, Fusarium* and *Colletotrichum* spp.).

- Although infection was usually widespread, symptoms often were not as severe as might be expected from previous 'run to waste' experience. This is possibly not a problem where the yield consists of cut stems or fruit, but when the root system is part of the product as in pot plants, the presence of sub-clinical infection could cause problems once plants leave the nursery.

- Treating recycled water before re-use successfully stopped the spread of infection and can significantly reduce disease symptoms. (NB water treatments have not been compared on a large scale in ebb/flood systems, which, depending how they are operated, can have an increased risk of plant-to-plant disease spread).

A number of water treatments have been shown to control disease spread successfully in recirculating systems, including: UV, ozonation, pasteurisation, microfiltration, the addition of chemicals (e.g. chlorination or additions of peroxy acetic acid (PAA)), and slow sand filtration (SSF). Of these, UV, ozonation, pasteurisation and microfiltration technologies are commercially available with 'off the shelf' units which can be installed following the suppliers advice. This is also true for chlorine dosing equipment for which there are long-standing dosing guidelines available from manufacturers of dosing equipment. There is also much useful technical information available on chemical sterilants through an HDC review (O'Neill and Berrie, 1992 HDC CP 4). At present, PAA is not registered as a pesticide and so cannot be used for disease control by dosing water. However, it is a very useful disinfectant with low phytotoxicity and can be used for cleaning beds and equipment between crops when a fast turn-around is needed. Guidelines are also available for the operation of SSF following MAFF and HDC funded research at HRI (Pettitt, 1996 MAFF HH1708SHN, 1997 HDC HNS 88, 1999 MAFF HH1733SHN, 2000 and unpublished HDC HNS 88b) and these will be considered further here. Many of the general guidelines for SSF costing, installation and operation apply to all water treatment techniques and where relevant these similarities will be pointed out in the following notes:

Water treatment techniques can be described as either ‘active’ or ‘passive’ disinfection (McPherson and Harriman, 1995). Active disinfection (e.g. UV, ozonation, pasteurisation or addition of chemicals) tends to kill all members of the microflora in the water indiscriminately, whereas passive treatments (e.g. microfiltration and SSF), do not completely remove certain groups of organisms such as fluorescent pseudomonad bacteria which are thought to play a role in reducing plant disease. Both types of system are effective at removing pathogen propagules from recirculated water, but current thought favours the use of ‘passive’ treatments in production systems where there is the possibility of introducing pathogen propagules from sources other than the water (e.g. plant material imported onto the nursery). The reason for this is that ‘active’ disinfection tends to reduce natural disease suppression downstream, whereas ‘passive’ dissinfection does not (and may even stimulate it in the case of SSF). There is still much we do not understand about natural disease suppression in irrigation water and research is continuing in this area.

The basic requirements for a system set up for cleaning recycled water include:

(i) a collection tank for water to be recycled,
(ii) water treatment system and
(iii) storage facility for treated water.

The sizes of these three components will be decided by:

a) the volume of water to be recycled/treated,
b) the recycling strategy,
c) the size of the production area and
d) the type of irrigation system being used
e) the water treatment system to be used.

The recycling strategy directly affects the volumes and quality of water to be treated. For example, if only the surplus water from an ebb/flood system is to be treated, the volumes of water for treatment would be much smaller than in a system where surplus water from beds is collected and treated together with greenhouse roof water. The quality of the waters in this example would also be very different in terms of EC, nutrient concentrations and the concentrations and composition of their microflora including potential plant pathogen propagules. Water quality is an important factor and will be briefly considered below.

The other aspect of the recycling strategy that will affect the volumes to be treated is whether recycling is intended to largely replace water usage from other sources such as mains and borehole, or merely to supplement it and minimise nursery runoff. The latter choice would obviously require a smaller treatment installation. If a replacement strategy is to be adopted then the sizes of the horticultural production area and the water source(s) to be recycled are deciding factors on the water volumes to be treated. In addition the irrigation system will greatly affect the volumes of water required as well as the volume and quality of the excess, recyclable water. Finally, the water treatment system will have some influence on decisions about the size of the storage facility for treated water. The size/capacity of the water treatment system and therefore capital and running costs and the space required, will influence the size of the storage facility and *vice versa*. A smaller treatment unit may not be able to supply the needs of the nursery on demand. However, if these systems are run continuously to a suitably-sized storage tank they would be satisfactory. This is essentially an economic decision based on treatment unit price, running costs and the availability/volume of clean water storage space.

It is wise to store treated water before use for two reasons:

a) to provide a 'buffer' for the inevitable times when 'troubleshooting' is needed on the treatment system (inevitably the hottest day of the summer!),
b) to provide a buffer' between treatment and application to crops, so that in the event of a suspected treatment breakdown, potentially contaminated, or chemically overdosed water is not applied directly to crops before testing and ameliorative treatment can be implemented.

Under ideal conditions a useful rule of thumb would be to set the size of the clean water storage to the volume of maximal ('worst case') daily demand plus a safety margin. However, the space available for such storage facilities is often limited, necessitating higher water treatment flow rates and possibly, therefore, larger treatment units and higher treatment costs.

In the case of SSF, the volume of water treated is directly related to the filter surface area; 1 m^2 of filter surface area will produce between 1 and 3 m^3 (approximately 220-660 gallons) per day depending on the sand quality used. More detailed information on filter structure and sand qualities is available in HDC reports HNS 88 and 88a (Pettitt, 1997 and 2000). It is very important to note that SSF is a biological process and requires oxygen, consequently the flow of water through the filter <u>must be continuous</u>. Storage space for the cleaned water is therefore essential for SSF operation, to store the water treated during times of the day (and night) when demand is low. Some commercially available SSF packages operate on an intermittent flow. However, observations at HRI Efford, of both experiments and samples from such systems on commercial nurseries, have shown that switching the flow on and off through a SSF often results in a breakdown in filter efficacy.

The decision as to what type of treatment system to use is ultimately going to be based on a combination of desired cleaning approach (i.e. 'active' or 'passive'), available space and treatment capital and running costs. The principles of water treatment installation are essentially the same whatever system is likely to be selected, so only SSF is considered here.

A SSF system would be installed between the dirty water and treated clean water storage facilities. Three aspects of the quality of the dirty water can influence the operation of the cleaning treatment:

1. suspended particles
2. oxygenation
3. electroconductivity (EC).

The most important of these is the amount of suspended particles, such as silt or peat fines, in the water. These need to be removed by some form of pre-filter (pre-filtration is a topic being dealt with in HDC-funded research at present: HDC HNS 88b). Pre-filtration is important for most water treatment systems, for example small suspended particles can cause ‘shadowing’ in UV systems, they can also sequester added chemicals and reduce their efficacy. In the case of SSF the problem is one of filter blockage.

Oxygenation and EC are both important with SSF action. As mentioned above, the biological action of SSF is aerobic and therefore it is necessary to make sure that oxygen levels are reasonably high in the water to be treated. This is easily achieved by splashing the water into the top of the filter. The effects of EC on SSF biology are not understood and this is an area that requires more research. High ECs (6 mS or more) have been linked to breakdowns in SSF efficacy. In the study reported here, nursery effluents only exceeded this on one nursery on a single occasion. The simplest way to deal with high ECs is dilution with water and if the rainwater is collected from greenhouse roofs for recycling, this is not a problem.

As outlined above, the size of the filter to be installed is decided by the planned capacity for storage (if this is limiting) or (better!) the maximum likely daily water demand. To this value, a ‘safety margin’ may be added. A conservative estimate of SSF flow rate would be 0.15 mh^{-1}, so the surface area of filter required to produce the desired volume of treated water in 24 h of running can be calculated in m^2 by:

$$((a + b) \div 24) \div 0.15$$

where: a = maximum daily water demand (m^3) and b = ‘safety margin’ (m^3). Using this simple formula, the sizes of filters needed to treat 60, 100 and 250 $m^3 day^{-1}$ can be estimated as 18.3, 30.6 and 76.4 m^2 respectively, given a 10% ‘safety margin’ (i.e. if circular tanks were used to house these filters, their diameters would be either, 4.8, 6.2 or 9.8 m respectively). More in-depth descriptions of SSF structure and function can be obtained from HDC reports HNS 88 and 88a (Pettitt, 1997 and 2000) as well as HDC workshops (contact Fiona Sheppard at HDC)

Installation costs for SSF can vary considerably depending on whether the filter is installed by contractors or ‘home built’. Commercially installed systems can cost anything from £10,000 to £30,000, depending on size and ‘extras’ such as pre-filters. Substantial savings can be made on this if the filter is constructed using on-site plumbing expertise, although staff time needs to be considered. Recent experience with a ‘home-built’ filter capable of processing 100 m^3 per day resulted in a total installation cost of just over £7,000. In addition to installation, the running costs need to be considered. The running cost that all treatment systems have in common is the power required to pump water from the dirty storage to the treatment system and from there to the clean storage. In addition to this, UV and ozonation systems require electric power to operate, and chemical dosing systems require a small amount of electricity plus a supply of chemicals. SSF may need cleaning occasionally (a simple process described in Pettitt, 1997 HDC HNS 88), although this need not be more frequent than once per year if the pre-filtration is working well.

Currently research on cleaning irrigation and feed water is focusing on two areas. Firstly there are the practical aspects (funded by HDC) of system operation, for example assessment of pre-filtration systems for water treatment systems. This work is being backed up by strategic work (largely funded by MAFF) looking into the biology of natural disease suppression in irrigation and biofiltration systems with a view to improving efficacy of operation. In particular this work is focused on attempts to increase SSF flow rates, which if successful would ultimately lead to future reductions in SSF size.

5. LEGISLATION AND PRACTICE IN OTHER COUNTRIES

5.1 The Netherlands

The detail of Dutch environmental legislation was given in HDC project PC 59a (Briercliffe, 1998). Since PC 59a was written Dutch growers are under further pressure to reduce pollution in accordance with targets being introduced between now and 2010. The law relating to glasshouse horticulture (known as AMvB) gives growers targets for reducing nitrogen, phosphorous, pesticide and energy pollution. Considerable negotiation is ongoing between the Dutch government and growers as to what these targets should be (Voogt, pers. comm.).

Individual nurseries are responsible for their own ‘Company Environmental Plan’ (CEP or BMP in Dutch) which is one popular method of conforming with the legislation. In this plan, growers make an agreement with the local authorities, to invest in certain equipment, training, etc., and state how this will help them to meet their agreed targets. As targets are set for nutrients, pesticides and energy, growers can work on one at a time if they wish. For example they can agree to invest in some new energy saving equipment one year and then agree on a different target area the following year.

This ‘covenant’ between the government and growers, known as GLAMI (GLAsshouseMIlieu) itemises detailed targets for each crop and type of growing system (Stanghellini, pers. comm.). The targets are presently being re-negotiated and are not yet published but examples of the current targets are shown in Table 8.

Table 8 - Targets for maximum permitted application or use levels by 2003 and 2010 (du Mortier, 1999).

Crop	Pesticides (kg active substance)		Energy (GJ/ha)		Nitrogen (kg/ha)		Phosphorus (kg/ha)	
Target year	2003	2010	2003	2010	2003	2010	2003	2010
Poinsettia	21.0	19.8	14640	13580	449.8	412.0	51.6	50.3
Rose	62.1	53.9	24143	21355	1098.8	872.0	215.6	203
Chrysanthemum	54.1	49.4	12945	11466	707.6	493.1	62.7	52.5

Although the targets are designed to reduce emissions they work by setting input targets. Measuring inputs within a particular growing system, is the only way of ensuring that growers are changing practices to conform with legislation. Growers are finding the pesticide targets particularly difficult to reach. For reducing nutrient pollution, the emphasis has moved away from targeting water application to specific restrictions on fertiliser use.

Growers are still very concerned about the targets. As production systems improve and become more intensive then the fertiliser application per given area may increase rather than decrease although the overall use (i.e. per volume of crop produced) will have reduced. The negotiations on these subjects will continue between Dutch growers, through their grower organisations and the government.

The government is largely using the MPS (Milieu Project Sierteelt), environmental accreditation scheme, for policing the legislation. Members of MPS must record all crop inputs and demonstrate reductions over time. At present 90% of Dutch growers are members of MPS. The remaining growers are not regulated by the scheme and therefore incur a higher risk of unannounced ‘visits’ from the local authorities.

The Dutch research stations are continuing to help growers comply with the legislation. Researchers at IMAG in Wageningen are aiming to use what is known about flows of water and pollutants in different crops to help growers achieve the GLAMI covenant targets. This will probably extend to research projects to help growers to further reduce their use of pesticides, fertilisers and energy (Stanghellini, pers. comm.)

This improved fertiliser and water application research has also been developing at the Proefstation voor Bloemisterij en Glasgroente (PBG) Naaldwijk (Voogt, pers. comm.). Their research has been done on nutrient losses from soil-grown glasshouse crops. Through use of careful fertigation fertiliser can be applied to these crops without leading to leaching to ground or surface waters (Voogt, *et al.*, 2000, in press). Research is also being done on the use of soil moisture measuring equipment as described in Section 2.1.

5.2 Germany

<u>Legislation</u>

The German public are very concerned about environmental issues. This is reflected in the German Parliament where the Green Party have been a significant force for the last fifteen years. The emphasis of German environmental law focuses more on quality than quantity. The government does not restrict water consumption although constitutional law does empower the government to do so if there is an extreme problem such as a severe water shortage. Currently there is not a water shortage in Germany (Freimuth, pers. comm.). However, the government has reduced water consumption through high charges. German households in some Landre (Regional Authorities), pay 13.50 DM/m^3 for water (supply and waste disposal); this is equivalent to £4.23 at the March 2000 exchange rate. Growers do not pay this rate unless they source from the mains and return waste to the mains system. However, growers using the mains supply still have to pay 4 - 5 DM/m^3 (£1.25 - £1.57) which is significantly higher than most UK growers. Water sourced from boreholes can cost up to 40 fenigs/m^3 (13p/m^3).

The main emphasis of German legislation is on pollution. It is illegal to pollute surface or groundwater in any way. The aim is for zero pollution but in reality this is virtually impossible to achieve. For those using nutrients, it is illegal to allow them to reach ground or surface water. For growers planting in the soil ‘Good Agricultural Practice’ must be followed. This states that soil must be tested before nutrient application. Tests should be carried out for phosphate every five years and two to three times each year for nitrate. The legislation applies to growers with more than 10 ha of land under outdoor or protected production. The legislation does not apply to container producers although these growers are encouraged to apply the same principles to avoid having more legislation imposed. The grower must pay for the tests although some landre initially helped growers by paying 50% of the costs.

The areas of particular concern have been designated 'Water Protection Zones' (Briercliffe, 1998. HDC Project PC 59a) which include the main horticultural production areas. The degree of controls imposed within these zones, depends on the proximity to the well or water source. The restrictions in these zones are defined as follows:

Zone 1	No irrigation within 30 m radius of the well.
Zone 2	'Closed' production systems only.
Zone 3	These are much larger areas and restrictions will depend on the risk to water. Controls will relate to nitrate and pesticide applications.

Within these zones the water industry, which is state run, has sought to work with growers to reduce the threat to water. This has been done in some regions, by employing a horticultural consultant to work with growers to help them comply with the legislation and implement any changes. The standards of cleanliness demanded from the German water industry are far higher than those in other EU member states and significantly stricter than those laid down in the EC Drinking Water Directive. In order to meet their obligations, the water authorities can exert pressure on consumers and polluters through pricing and media publicity. They can easily 'name and shame' water users considered to be unhelpful in their quest for clean water.

Germany also has other laws covering soil protection and pesticides. More legislation is expected including an all embracing 'Environment' law which will bring together the various strands of related legislation. This will undoubtedly introduce more regulations which will affect growers.

Enforcement

Environmental legislation is enforced by a national 'Environmental Agency' as well as by agencies within each of the sixteen federal states. The legislation is not easy to enforce as the requirements are so unrealistic but enforcement is tightening up particularly within the Water Protection Zones.

Changes in production methods for protected ornamentals

German growers have responded to environmental legislation and water costs by installing 'closed' systems where there is no nutrient release to the environment. It is estimated that 60-70% of protected ornamentals nurseries are using closed systems (Molitor, pers. comm.) and virtually all investments over the last 10 years have been in closed systems. The government did provide financial help to growers to convert to closed systems in one of the German landre. Growers were offered 40-50% of the investment costs. This was gained through a tax on consumers of 10 pfennigs/m^3 of water used, which was to be invested in water saving. However, this financial help is no longer available and no other grant schemes exist.

Most research work is based on the use of closed systems. Research on minimising water application to reduce leachate is not justified as it is not considered to be a commercially significant issue. Closed systems tend to be either ebb and flow flooding systems or overhead applications where water is collected and recirculated. Nurseries only treat recirculated water (for pathogens) when sub-irrigation systems are not used. Researchers at Geisenheim, along with German growers, are convinced that disease spread does not occur in sub-irrigation systems when healthy crops are not excessively irrigated. They claim that water does not leave a pot once it is taken up and therefore there is no potential for pathogen spread. This agrees with work carried out in the USA (Reed, 1996). Overhead systems do require water treatment and most growers use slow sand filtration technology. Some growers have more recently found granulated rockwool in slow filters to be more effective than sand.

The focus of research in Germany is on reducing nutrient losses. Although this is largely achieved by reducing water consumption the benefits of water savings are not the main focus. However, there is considerable interest in the use of tensiometers. Growers are increasingly using this technology to reduce water consumption but, perhaps more significantly, to control crop growth. Typically growers insert a tensiometer into one reference plant within a growing area (with the same conditions and crop). The tensiometer is used to trigger the onset of irrigation when, for example, the tension reaches 120 kP and then switch off when the tension drops below 50 kP. The reference plant used would represent the plant with the highest water consumption to ensure all plants are adequately watered.

Research has been carried out at Geisenheim using tensiometers on Poinsettia and *Pelargonium* to assess crop growth in different water and fertiliser regimes. There are many implications for crop growth and models are being developed for using water application to control crop growth. The regime for greatest restriction on *Pelargonium* (plants kept at 400 ha/Pa) led to more water being taken up at each watering but overall a third lower water consumption by the crop.

Some problems were experienced with Poinsettia crops where low water regimes caused leaf scorching and uneven branching so clearly more work is required to develop models for control of plant growth by water use.

5.3 Australia

Due to the hot climate and scarcity of water, growers in Australia are under pressure to reduce water use. Legislation that relates to nursery run-off has been developed on a regional or state basis, therefore not all areas are under the same legislation. The area with the toughest specific legislation on this subject is New South Wales (NSW). In other areas, such as Victoria, the industry has been given time to 'self regulate' (Hall, pers. comm.).

It is likely that any new legislation will focus on nurseries as 'point sources' for pollution. The state Environmental Protection Agencies (EPA) have identified nurseries and retailers as potential point source polluters and the industry is aware that it needs to deal with waste water. Up to 70% of nurseries treat their waste water before re-using it or allowing it to leave the nursery. Growers have to demonstrate that they are willing to put effort into reducing contaminated waste water in order to avoid the introduction of specific legislation (Hall, pers. comm.).

The possibility of fines coupled with the increasing price of water is making growers look seriously at the issues. Growers can see the advantages in adopting closed sub-irrigation systems from both a financial, environmental and marketing point of view. Industry accreditation schemes are also helping to focus the minds of growers on the issue (Hall, pers. comm.). The Nursery Industry Accreditation Scheme, Australia (NIASA) requires that all irrigation water, from surface supplies and re-used water, be effectively disinfected. NIASA is a scheme for all growers of nursery stock and growing media suppliers (Atkinson, pers. comm.).

In response to these pressures the use of sub-irrigation systems is slowly being adopted. As in the UK this tends to be a combination of ebb and flood, capillary matting, sand beds and drip systems. However, many nurseries are simply trying to make their overhead systems more efficient. 'Water Works' workshops carried out by the regional extension services have been particularly effective in helping growers to do this. Many growers have achieved 30% or better reductions in water use along with improved crop uniformity as a result of applying the recommendations (Atkinson, pers. comm.). An evaluation of the workshops showed that 70% of systems are applying water at a higher rate than the potting media can absorb, producing excessive nutrient leaching. It showed that 87% of systems are applying water so unevenly that about two to three times the water volume is required to effectively water the plants. Only 7% of the systems tested were using water efficiently enough to implement scheduling techniques and obtaining maximum benefit from fertiliser applications (Rolfe, 1998).

Some growers collect run-off and treat it using various methods before re-use. The methods most commonly used include chlorine, chloro-bromine, chlorine-dioxide and UV. As in the UK Australian growers are beginning to develop slow sand filtration and adopt this for water treatment (Hall, pers. comm.).

On the whole it seems that Australian growers are at a very similar stage to those in the UK. Most use 'open' systems, usually applied overhead although increasingly they are turning to some form of sub-irrigation. They are addressing the issues of water management seriously. This can be seen from the publication of 'Managing Water in Plant Nurseries' (Rolfe *et.al*, 1994) which is a substantial book designed to help growers in this area. The book was funded by industry research funding and a new edition will soon be available. Other booklets have also been produced on this subject from industry research levy funding (Atkinson, 1997).

5.4 USA

As in Australia, the responsibility for environmental protection lies with individual states. Some states, such as Oregon, have strict controls over nutrient leaching to land and water courses. Many irrigation systems in the USA are overhead although there is an increasing use of ebb and flow flood benches in pot plant production. Research work and guidance for US growers on this subject is typically carried out by the University Extension Services in different states. Those in Oregon, Massachusets and Texas have been particularly active in promoting this work. Much of the work cited in Section 2.1 was carried out in US Universities.

This research has focused on reducing water application through the type of irrigation system and reducing fertiliser leaching by the same means. Extensive work has been carried out in the USA on controlled release fertilisers (e.g. Cox, 1993) but results from the USA and Australia may not be directly applicable to the UK situation. The differences in temperatures, light levels and humidities affect water and fertiliser use and results will not always be the same in the UK.

Many Extension services produce guidance notes for growers on the subject of water and fertiliser conservation and publications; Cox (1996) provided a useful overview of research to growers. In many states growers are now under pressure to recycle water (Sheldon, 2000; James and van Iersel, 1998) either through legislation or for quality reasons. Many of the recommendations in Section 8.3 come from learning experiences in the USA. An example of this is highlighted in a survey carried out on growers using 'zero-effluent systems' (i.e. ebb and flow flooding systems, Wen-fei, *et al.*, 1998). The survey showed that growers that had installed zero-effluent systems had done so primarily to improve crop quality, increase production efficiency and to provide greater control over the production system. Legislation and environmental concerns were not considered to be as important. Of the growers recirculating water 84% did not treat it for disease before re-use. Of these, 78% had never had pathogen problems as a result, 20% said that disease levels had been reduced by using the zero-effluent system and only 2% reported disease problems attributed to the use of untreated recirculated water. Of those surveyed 83% reported reduced fertiliser applications as a result of the new systems and 83% said that installation of the zero-effluent systems would pay for itself although this may take a few years.

6. EXISTING AND PROPOSED LEGISLATION IN THE UK

This section outlines some of the existing and proposed legislation which could affect growers. However, expert advice should be sought before taking any action which could result in pollution, or if there is any doubt about the legality of current practice. This section repeats the relevant information provided in PC 59a (Briercliffe, 1998) and updates other areas as appropriate.

Summary of legislation implications for protected ornamentals growers

As shown in this section, there is a considerable amount of legislation relating to nitrates; most is in an agricultural context, with smaller scale horticultural enterprises being less affected.

Most of the legislation against water pollution either regulates large scale agriculture or large industry and sewage works. Figures are given in the Nitrate Directive for values of N per hectare which should not be exceeded, this covers both direct application to soils and soil-grown crops. However, no provision is currently made for protected ornamentals or containers as far as nutrient regulation is concerned.

Although fertilisers are rarely applied directly to soils in protected ornamental production, there can still be considerable run-off of nutrients to the ground. The area under protection can become a point source of pollution, possibly exceeding agricultural levels. Therefore, the following aspects of legislation should be adhered to:

- **Water Resources Act 1991 - follow the new horticulture sections in the MAFF 'Water Code'**

- **Groundwater Regulations 1998 - Ensure that these regulations are complied with and listed pesticides and fertilisers are only disposed of onto authorised sites.**

- **FEPA - Prevent water contamination with pesticides by following the regulations.**

- **Drinking Water Directive - Ensure run-off is not causing nitrate levels in adjoining watercourses to exceed the limit of 50 mg/l nitrate.**

- **Water Abstraction Licensing - Obtain a copy of 'Taking Water Responsibly' from DETR and plan future abstractions and water uses in the light of these proposals.**

Horticultural enterprises should be seen to be minimising nutrient and pesticide run-off in order to prevent heavily enforced legislation being imposed in the future. However, in preparation for enforced legislation, growers need to be ready and have a strategy to reduce nutrient and pesticide waste.

Laws Controlling Pollution

Water Resources Act (WRA) 1991

Water pollution control is mainly governed by the Water Resources Act (WRA) 1991. The legislation stipulates that:

1. Prosecution will occur if pollution is detected.

2. Measures to prevent pollution must be taken. The Environment Agency (EA) is responsible for enforcing this legislation.

Section 85 of the Water Resources Act 1991 makes it an offence to cause or knowingly to permit a discharge of poisonous, noxious or polluting matter or any solid waste matter to enter controlled waters. It is also an offence to allow matter to enter water so as to obstruct flow and aggravate pollution. “Controlled waters” means all ground water, coastal or inland waters including rivers, streams, ditches, land drains and most other passages through which water flows, and most lakes and ponds (Anon., 1992). One can “cause” pollution without acting intentionally or negligently.

However, an offence is not committed under Section 85 if authority to make the discharge has been given. This usually means a consent to discharge issued by the EA under Section 88 of the Act. In practice few farmers apply for discharge consents. The strengths of the wastes involved, the lack of dilution usually available, and the costs of treating the wastes to a form that might be acceptable to discharge, make it unlikely that an application for a discharge consent for most farm wastes would be acceptable to the EA (Anon., 1992). Situations where wastes may be discharged to controlled waters under a discharge consent include intensive livestock units, which may be able to justify the costs of a treatment plant; and where the polluting effect of the waste is relatively weak, e.g. with vegetable washings.

Consents to discharge may be reviewed and the EA has a duty to review them periodically. This may result from circumstances in, for example, an individual river or by the Government responding to European Directives on water quality.

Groundwater Regulations 1998

The Groundwater Regulations came into force on 1 April 1999. They were introduced at relatively short notice as the government sought to comply with the EC Groundwater Directive. The Regulations were primarily initiated following concern about pesticide pollution from disposal of spent sheep dip. The Regulations affect all growers that dispose of any type of pesticide to land. Disposal of waste pesticide (including tank washings) to land is prohibited unless it has been authorised by the EA. Growers who applied for authorisation prior to 31 March 1999 can continue current practices until they receive authorisation (which will contain conditions) or their applications are refused (Briercliffe, 2000). These new regulations group chemicals into two lists; List I consists of the more harmful substances, including pesticides and List II lists other substances of concern. Ammonia, nitrites and phosphorus are in List II; these are substances which may be typically released from horticultural premises. The proposed regulations state that an authorisation to introduce these substances into groundwater, shall not be granted in relation to:

1. Any direct discharge of any substance in List I or II.

2. Any disposal or tipping for the purpose of disposal of any substance in List I or II which might lead to an indirect discharge of that substance.

3. Any other activity on or in the ground which might lead to an indirect discharge of any substance in List I or II.

Such authorisation is not granted unless that activity has been subjected to prior investigation. This prior investigation is the responsibility of the EA which has the powers to grant authorisations. Growers are advised, in the first instance, to contact the local office of the EA. However, the main areas where the regulations affect growers are as follows:

- The disposal of pesticides to land, including the disposal of washings. This practice must either discontinue (by careful calibration and application of washings to the crop) or the disposal site must be authorised.

- The discharge of unused fertiliser solution (i.e. any solution containing List II substances) must be authorised by the EA. This affects growers that use recirculating systems which need an annual cleaning out. Authorisation for this is required unless the grower can demonstrate that the discharge of this solution onto land is of direct agricultural benefit.

- Where run-off collects in a drainage or ditch system, before draining into the ground or water courses (drainage into a mains supply should already have authorisation). This drain or collection system requires authorisation from the EA. This is of particular concern as any point source of discharge requires authorisation. This is an area that the EA have not yet confronted individually. However, as other aspects are dealt with then the EA will implement the regulations in full.

- General run-off (which is not collected) may also require authorisation. However, this gradual seepage of List II substances is of a lesser concern to the EA. There is scope, within the regulations, for the production of codes of practice which may, in time, cover issues such as this. In all cases growers should contact local EA offices for clarification on particular circumstances.

The authorisation will be granted as long as the conditions are met. These conditions can be extensive and include precautionary measures, maximum quantities and arrangements for monitoring. The cost of this authorisation procedure will be borne by the one seeking to make the disposal (i.e. the grower).

Since the introduction of these regulations the EA have had a number of problems with horticultural businesses. Many of these holdings are relatively small and do not have much land area available for pesticide disposal. The EA prefer to see waste disposed of over large areas to help reduce the concentrations in small areas. Where appropriate compromises cannot be found then authorisations will not be granted and growers will be required to find alternative methods for the disposal of listed substances.

Pollution offences are regarded very seriously and carry a penalty of up to £20,000 in the Magistrates court and an unlimited fine in the Crown court. It may also be necessary to pay for any damage caused by the pollution.

Other discharge legislation within the Water Resources Act

Section 85 of the Water Resources Act does not automatically cover all types of discharge, including discharges to land and certain lakes or ponds. However the EA can prohibit such discharges in particular cases by issuing so-called "relevant prohibitions" under Section 86. This power is limited to discharges "from a building or from any fixed plant" - a restrictive definition which raises complications in the case of certain farm waste disposal systems (Anon., 1992). The Groundwater Regulations, described above, extend the EA's powers in dealing with discharges to land.

Section 93 and schedule 11 contain powers to designate "Water Protection Zones". Activities likely to result in water pollution can be restricted in these areas. The EA is responsible for proposing designations to the Secretary of State. This would be in addition to the existing Nitrate Sensitive Areas and Vulnerable Zones (see below).

Section 161 allows the EA to carry out operations to prevent or clean up pollution and recover the costs from the person responsible (the "polluter pays" principle). Under Section 202 the EA can ask farmers and growers for information which will assist in carrying out its job preventing water pollution.

Section 97 provides for Ministers to approve Codes of Good Agricultural Practice (CoGAP). The latest CoGAP for water was published in 1998 and is a practical guide to help farmers and growers avoid causing water pollution. Non-compliance with the code does not necessarily give rise to civil or criminal liability but it could be taken into account in any legal action. Following the code is not a defence against a charge of causing pollution.

The Code contains a section on specialised horticulture and covers soil-grown protected crops, hydroponic protected crops, container nursery stock, organic wastes, other wastes, mushrooms and watercress. It means that some growers would be advised to implement new pollution measures. For example, the Code suggests that for non-recirculating hydroponic systems growers should be encouraged to measure water application rates to ensure that they do not exceed crop requirements plus a reasonable (<30%) excess. For these same systems, excessive run-off should be avoided by using the following techniques:

1. Measure the quantity of run-off at a representative number of points in each cropping area (the code gives details on a method which can be used for measurement). Compare the measurement with standard figures, where available, of run-off for annual water use. Water application should be reduced if run-off is more than 30% of the water being applied.

2. Make sure the irrigation system is well designed, carefully installed, monitored closely and regularly maintained to ensure that the variability in the amount of water delivered by each nozzle or dripper is as low as possible.

3. The amount and frequency of applications should be adjusted according to the needs of the substrate and growing system. For example, more frequent applications of smaller volumes are needed for less retentive substrates.

4. Addition of nutrients to the water for protected crops should be matched to the crop requirement, particularly stage of growth and time of year.

For hydroponic recirculating systems, the amount of solution in the holding tanks should be allowed to decrease as much as possible before the end of cropping to prevent large discharges when the tanks are emptied.

For containerised nursery stock, the Code suggests minimising run-off wherever possible by using sub-irrigated sand beds if these can be afforded. Or if overhead irrigation is used, the system should be carefully designed to match the cropped area and irrigation nozzles should be regularly maintained to ensure even water application.

The Code suggests that new container areas should be planned with the possibility of water recirculation in mind. It also commends the use of controlled release fertilisers and suggests that the amount of nutrients added to both compost and water should be carefully matched to the production system to minimise the amount lost in run-off. Nutrient levels should be monitored to minimise costs and run-off loss.

The Code does not specifically mention protected ornamental crops which are often not grown in soil or in hydroponic systems. However, the conditions relating to containerised nursery stock and nutrient input would probably also cover protected ornamentals.

The Codes of Good Agricultural Practice written for air (1992) and soil (1993) have also been revised and 1998 editions are available.

The Urban Waste Water Treatment Directive (91/271/EC)

This Directive was introduced to protect the environment from the adverse effects of discharges from sewage treatment works and from certain sectors of industry. It is implemented through the Urban Waste Water treatment (England and Wales) Regulations SI 1994/2841. These define the EA as the competent authority.

The Directive requires the identification of Sensitive Areas using indicative standards expressed in terms of nitrate (95% of samples taken should contain no more than 50 mg/l nitrate), phosphate, dissolved oxygen, plant biomass, clarity, retention time and biological effects. Different criteria are applied to estuaries and coastal waters, still freshwaters and running freshwaters. Waters can only be identified as Sensitive Areas under the Directive, if a qualifying discharge is contributing to problems. In such cases nutrient removal is required, unless it can be shown that this is not the cause.

Whilst this Directive directly targets eutrophication, it is mainly targeted at large sewage works impacting in designated Sensitive Areas. It may come into effect against extreme agricultural polluting sources but does not provide the complete answer for controlling eutrophication. The EU is currently working towards a Framework Directive on Water Resources, which aims to integrate different aspects of policy. This will tie in many of the aspects of different legislation e.g., whereas this directive deals with sewage works and the Nitrate Directive deals with agriculture, the EU are aiming to draw it all together in one Framework Directive. In theory this new framework should not bring about new legislation. However, in practice where laws from more than one country are combined, some changes are inevitable. The framework should give authorities a stronger hand in controlling diffuse pollution and place emphasis back on pollution prevention.

EC directive on water quality for freshwater fish (78/659/EEC)

This Directive sets water quality objectives for stretches of rivers and other fresh waters needing protection or improvement in order to support fish life. These objectives are to be achieved through pollution controls and reduction programmes.

Food and Environmental Protection Act (FEPA) 1985, Control of Pesticide Regulations 1986, and Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1990)

The regulations which have been issued under FEPA Part III set out detailed laws for the approval, supply, storage and use of pesticides. One of the basic conditions laid down for the use of pesticides is that users take all reasonable precautions to protect the environment and “in particular to avoid the pollution of water”. People who use pesticides must be competent and have received proper instruction.

The Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1998) gives guidance on pesticide use and precautions to be taken to prevent water pollution. In particular, the Code contains advice on possible routes for disposing of dilute wastes and washings, highlighting the need to ask the EA for advice where disposal is to land. Similar advice is also contained in the 1998 CoGAP for water. FEPA contains powers to control the levels of pesticide which may be left in any crop, feed or feeding stuff.

Environmental Protection Act (EPA) 1990

The Environmental Protection Act 1990 updates the UK's pollution control systems. It stipulates a system of integrated pollution control for the disposal of wastes to land, water and air.

Part I establishes integrated pollution control and gives local authorities powers to control air pollution from a range of prescribed processes; Part II improves the laws for waste disposal; and Part III covers statutory nuisances and clean air. A new waste management licensing system was put in place by the Waste Management Licensing Regulations 1994, although most agricultural activities are exempt. The DETR (Department of Environment, Transport and the Regions) is expected to consult on the application of controls to agricultural waste during the summer of 2000. If this exemption is removed it could have a significant impact on growers making waste peat and polythene, for example, to be 'controlled waste'. It is likely that there will be strict instructions for the disposal of controlled waste although composting will be encouraged. Those using composting as a means of waste disposal will have to inform the EA and demonstrate that this is taking place. It is unlikely that these regulations will class nutrient run-off or excessively applied water as waste.

Environment Act 1995

This Act does not replace the EPA (1990) or the WRA (1992) acts, but was introduced for the main purpose of enabling the setting up of the Environment Agency. It also gives the EA new duties which overarch the EPA and WRA with relation to sustainable development and conservation. In real terms, this means there will be no decisions on functional changes in legislation without the EPA and WRA now considering an extra tier, which includes development and conservation.

Planning Law

Environmental Assessment Directive (85/337/EEC) and the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988

These regulations set out the requirements for the Environmental Assessment of certain major developments for which planning permission is needed. Most agricultural projects are exempt from planning control and hence from the procedures established under the Directive requiring environmental assessment of projects likely to significantly affect the environment. Certain projects may, however, be subject to assessment: these include, for agriculture, projects which involve water management, poultry and pig rearing.

If a grower plans a project which requires Environmental Assessment, he is responsible for carrying out the assessment. If a proposed project is likely to affect water quality or water resources, the EA is interested to see that there are likely to be no adverse effects (Anon., 1992). This applies to clean surface water as well as run-off; large volumes of water are collected from glasshouse and shed roofs and concrete areas during rainstorms and could overload ditches. The EA may require an Assessment to be carried out following a water abstraction application. Carrying out this Assessment can involve considerable cost to the grower and in many cases costs far more than the other licensing and advertising costs which are incurred. The EA may want to know about the impact of the abstraction on other users, surface water, local geology, hydrogeology and water flows. They may also require ecological and engineering surveys to be carried out. The appropriate body may also be consulted if there are plans to build in an Environmentally Sensitive Area (ESA), National Park, on Sites of Special Scientific Interest (SSSI's) or on archaeological sites.

Control of the Use of Water

Water Act 1989

Water Resources Act 1991

Most people who need to abstract water from a "source of supply" need an abstraction licence. A source of supply can either be an inland water (e.g. river) or ground water. Abstractions of less than 20 m^3 per day, which fulfil certain requirements as to location, do not need a licence. Interestingly this could mean that some nurseries using efficient ebb and flow systems, could operate without a license. For example a typical ebb and flow system needs approximately 4 litres/m^2/day. As long as less than 20,000 litres was used per day then an ebb and flow system up to 5000 m^2 could be used without a license (Bragg, pers. comm.). It is an offence to abstract water without a license or not to comply with the terms of a license. The EA may impose temporary restrictions on abstraction of water for use for spray irrigation, if an exceptional shortage of rain or other emergency makes that necessary (without having to pay compensation). Such restrictions can only relate to groundwater abstractions where that is in turn likely to affect the flow of an inland (i.e. surface) water (Anon., 1992). At present growers of protected crops are exempt but growers of outdoor nursery stock are not.

Most growers will be aware that the government conducted a consultation on changes to the water abstraction licensing system in England and Wales. Their decisions, following this consultation, are published in a DETR publication 'Taking Water Responsibly' (Anon 1999b). These changes are expected to come before Parliament as soon as Parliamentary time is allocated. The consultation was extensive and an exhaustive list of all the changes cannot be made here. It is recommended that growers using abstracted water obtain a copy of the above publication from DETR (DETR Free Literature, Tel: 0870 1226236).

The most significant effect of the changes on protected ornamentals producers will come about during a review of existing licenses. By 2003 all abstraction licenses will be reviewed. During this review the agricultural and horticultural sector cannot expect to be treated more favourably than other industrial sectors, as has been the case in the past. The way that water is used by each abstractor will be reviewed as well as the quantities abstracted. The way in which this legislation will be enforced is not known yet but it is likely that growers found to be using excessively inefficient irrigation systems and those wasteful of water, may have their licenses withdrawn or permitted volumes reduced. Growers not presently using all their permitted volumes may be required to surrender licences that are surplus to requirement. The environmental impact of abstraction will also be considered in all future applications.

It is becoming increasingly difficult to obtain permission to abstract water from ground and surface water sources. It is very rare that summer abstraction licenses are granted and where new abstractions are permitted these tend to be for winter abstraction for storage. Licences can take a considerable time to obtain. Simple abstractions can take six months and more complex applications (i.e. where pump tests are required) can take up to eighteen months. Virtually all new licences are time-limited and it can take some time to negotiate a reasonable time period with the EA.

It is clear that future abstraction will be regulated in much more detail. Rather than granting new permits for abstraction the EA are likely to share out existing authorisations and require significantly more justification for use of abstracted water. This is a major financial consideration for growers not using mains water. Water efficiency will cease to be a side issue and will become increasingly important as authorities seek justification for all water uses.

Nitrate Sensitive Areas Scheme

The NSA scheme provides an opportunity for farmers in certain, selected areas of England, to receive payments in return for voluntarily helping to protect valuable supplies of drinking water. A Nitrate Sensitive Area is an area where nitrate concentrations in sources of public drinking water exceed, or are at risk of exceeding, the limit of 50 mg NO_3/l laid down in the 1980 EU Drinking Water Directive and where voluntary, compensated agricultural measures have been introduced as a means of reducing those levels. The NSA scheme consists of 22 areas in England, covering approximately 35,000 ha, over 28 nitrate vulnerable groundwaters. This voluntary scheme has now been withdrawn by the government. Existing members of the scheme will be able to continue until their five year contract is over, after which the scheme will finish.

Laws Relating to Drinking Water Quality

Much of this legislation originates from the EU in the form of Directives. These are instructions to the UK Government, and other EU member states, to take steps in domestic law which will carry out the objectives of the Directive. Environmentally orientated Directives tend to operate by setting standards (e.g. for drinking water quality). The Government, through the EA, then has to meet these standards by taking whatever measures will achieve them.

EU Surface Water for Drinking Directive (75/440/EEC)
EU Sampling Surface Water for Drinking Directive (79/869/EEC)

The objective of the first of these Directives is to ensure that surface water abstracted for use as drinking water, prior to treatment, reaches certain standards and receives adequate treatment before being put into public supply; the second deals with quality measurements.

EU Drinking Water Directive (80/778/EEC)

This has been implemented under the Water Industry Act (1991) and the Water Supply (Water Quality) Regulations 1989 and amendments in 1989 and 1991. The Regulations incorporate all the standards (maximum admissible concentrations MACs and minimum required concentrations MRCs) set out in the EU Drinking Water Directive. They also include 11 national standards. In total, numerical standards are set for 55 parameters and descriptive standards for a further two parameters. In addition to these standards applying to water at the time of supply, a number of standards apply to water issuing from treatment works and to water held in service reservoirs within the distribution system.

Statutory responsibility is placed upon the Water Companies, but they are subject to checks by local authorities and by the Drinking Water Inspectorate. Monitoring information must be made publicly available.

The EU Drinking Water Directive (1980) sets standards for various substances in drinking water supplies. For nitrate, there is a “guide level” of 25 mg/l NO_3 and a MAC of 50 mg/l NO_3. The EU limit refers to *nitrate*. However, most growers are used to dealing in terms of nitrate-N. To convert from a nitrate (NO_3) concentration to nitrogen (N) it is necessary to divide by 4.427. The EU limits thus become 5.6 and 11.3 mg/l, respectively. Values are quoted as nitrogen (N) throughout this report. Often the designation nitrate-N (NO_3-N) is used to distinguish from ammonium-N (NH_4-N).

The EU Drinking Water Directive also sets standards for pesticides and related products in water. At the time of supply a limit is set of 0.5 μg/l for the total of the detected substances and for an individual substance 0.1 μg/l. Pesticides are defined as fungicides, herbicides and insecticides and the related products refer to polychlorinated biphenyls (PCBs) and terphenyls. The Directive’s standards were set at the limit of detection for organochlorine insecticides in order to minimise the occurrence of pesticides in drinking water and they were not based on toxicological evidence (Hydes *et al*., 1992). The World Health Organisation adopts a different approach from that of the European Union. It considers the toxicology of individual substances and recommends a guideline concentration for each substance based on the assumption of lifelong consumption at that concentration.

Nitrate Directive

In December 1991 the European Union Nitrate Directive (91/676/EC) was adopted by member states; this may impact on intensive horticulture. The Nitrate Directive aims to limit nitrate contamination of drinking water and prevent nitrate limited eutrophication. (“Eutrophication” is the term used to describe what happens when the nutrient content of natural waters is artificially raised; there may be excessive growth of aquatic plants e.g. reeds and algae and periodic fluctuations in parameters such as dissolved oxygen and pH).

The Directive states that the application of total nitrogen from organic manure over a whole farm should not exceed 210 kg/ha (170 kg/ha from 19 December 2002). This value includes nitrogen in manures and urine deposited while livestock are grazing. The legislation impinges mainly on arable and livestock farmers and will impinge only within designated Nitrate Vulnerable Zones (NVZs).

The Directive includes diffuse losses of nitrate from agriculture and so excess nutrient allowed to drain into the soil would be covered. Both ground and surface waters are included.

The Directive required that by 1994, "vulnerable zones" were to be designated. These are areas of land draining directly or indirectly:

a) into drinking water sources (both ground and surface water) which contain or could contain more than 50 mg/l nitrate (11.3mg/l NO_3-N),

b) into waters which are, or may become, eutrophic (with nitrogen as the limiting factor).

By the end of 1995, action programmes were to be drawn up specifying what farmers in the vulnerable zones had to do to reduce nitrate losses. There are currently 68 NVZs in England and Wales which were designated in 1996. The NVZs place no specific requirements on protected horticulture and do not cover N applications to containerised crops.

The UK has drawn up action programmes, which came into force on 19 December 1998 (Anon, 1999). The action programmes are based on "good agricultural practice", including rules on:

- The timing, rate and other conditions of fertiliser applications, both organic and inorganic, to ensure that the crop does not receive more nitrogen than is economically justifiable. e.g. organic manure application must not exceed 250 kg / ha /year of total N.

- Closed periods, e.g. for slurry spreading, and storage capacity to be sufficient to cover the longest period during which application is forbidden. Closed periods for application of N fertilisers to arable land are from 1 Sep to 1 Feb; for application to grassland the period is 15 Sep to 1 Feb. Closed periods for application of organic manures to arable land are from 1 Aug to 1 Nov; for application to grassland the period is 1 Sep to 1 Nov.

- The overall quantity of N per ha which may be supplied by animal manure including that deposited while grazing, (normally not more than 170 kg/ha with a higher limit of 210 kg N/ha for the first four years after the measures come into effect).

Further plans to extend NVZs are likely to be put out for consultation during the autumn of 2000 (Marks, pers. comm.). These plans include the monitoring of all freshwaters, not just drinking waters. It is expected that this extended testing will lead to the designation of new NVZs and that the majority of new designations will be in central and eastern England.

Although NVZs do not place any specific restrictions on protected horticultural production, the effectiveness of NVZs are constantly being reviewed. If it was found that the agreed strategies are not sufficiently reducing nitrate levels then other production areas, including glasshouse production, may also be investigated. It is in the interest of growers to minimise nitrate losses from premises, especially if within a NVZ, to avoid bringing protected horticulture within the scope of the Action Programmes.

7. CONCLUSIONS AND KEY RECOMMENDATIONS

7.1 Conclusions

Growers of protected ornamentals are presently wasting water and money through inefficient production systems. Irrigation tests carried out in this research showed that capillary systems lost between 54 and 89% of the water applied, drip systems lost between 11 and 47%, trough track lost 87%, overhead spraylines lost 55% and hand-watering lost between 8 and 78% (Stage 1 tests, Appendix II).

This 'lost' water was either evaporated or lost as run-off from the glasshouse. The water contained liquid feed which was being lost in the same proportions to the environment. The value of the fertiliser wastage was as high as £450 for every 10,000 plants grown in one of the capillary systems tested (Figure 11).

Recirculating systems waste very little water and fertiliser but require higher investment costs. Non-recirculating systems can be modified or treated differently to improve the efficiency of water and fertiliser use. This is highlighted by the range of water losses identified for each system above. Key conclusions on each production system are identified below with greater detail presented in Section 3.4.1.

- Ebb and flow and trough track systems should be designed with built-in recirculation. Water tanks should be allowed to run down to low levels before emptying out.
- Capillary systems should apply water 'little and often' and ensure the use of high quality level matting.
- Drip systems offer good water saving potential for pot production as long as drippers are regularly checked.
- Hand-watering systems can be efficient if supplemented with capillary matting and careful application by trained staff.
- Spraylines are difficult to improve and inherently inefficient. Careful choice of nozzles can help to reduce the loss of water onto paths.
- Gantry systems provide well targetted water application. Shutting off nozzles irrigating hard surfaces can reduce wastage.

Water costs remain a relatively minor component of production costs. Based on a mean cost of mains water of £0.67/m^3 the cost of irrigating 10,000 plants would be approximately £66 for nursery A, £25 for nursery B, £51 for nursery C and £63 for nursery D. However, in some regions water costs are rising and when water abstraction licences are reviewed many growers may have to turn to the mains for their water supply.

This research has proved to be something of an 'eye opener', not least to many of the participating nurseries. It has been interesting to see how little most growers really know about the quantities of water and fertiliser that they use and waste. Some of the findings have been alarming whereas others have given more confidence for improving efficiency in the future.

The industry has been concerned for some time about the pressures of European legislation and how these might be implemented in the UK. Some believe that it is inevitable that in time the UK industry will have to move to entirely ‘closed’ production methods such as in countries like Germany and The Netherlands. However, this need not be the case if the UK industry acts now to reduce the environmental impact of its activities.

This research highlighted some nurseries where water and fertiliser were clearly wasted and the levels of fertiliser going into the ground may well be high enough to cause ground or surface water pollution if soil types and local geology lend themselves to it. Many of these nurseries would not wish to be branded as ‘polluters’ and fortunately potentially polluting nurseries appear to be in the minority. However, where the appropriate environmental authorities discover these practices then the industry would only have itself to blame if strict legislation was introduced.

UK growers would not wish to be forced to produce in ‘closed’ systems, although many may choose these systems as they offer many advantages for crop production. Growers should carefully consider the options presented in this report and seriously review their current practice. Systems that pollute the environment will almost certainly prompt strict legislation. Small changes in practice today could ensure cost savings in the future. Many businesses in The Netherlands went out of business when forced to move to ‘closed’ systems. The situation would be the same in the UK unless it is demonstrated that the systems and practices used take full account of environmental considerations.

7.2 Key Recommendations

It is important that growers are made aware of the findings of this research to ensure action is taken to reduce water and fertiliser losses to the environment.

- Growers should be made aware of the methods that can be adopted to reduce losses by use of alternative systems and changes in practice in existing systems. A series of workshops across the country may help in this and/or carefully designed leaflets or manuals.

- Growers need to be made more aware of the role of growing media in managing water and fertiliser application.

- A number of capillary matting products and systems are available to growers but there is little independent information on which products growers should use. It is recommended that research is carried out to assess the properties of the products available to aid recommendations to growers.

- A range of soil moisture-measuring products are on the market and some growers have 'experimented' with them. Research is needed to assess which of these are most effective and how they can be appropriately used by UK producers.

- Growers should be encouraged to check the efficiency of their own irrigation systems and include this in training to staff.

- Growers should be made more aware of the importance of monitoring water quality and how to interpret laboratory analysis.

- Further research is required on using water for growth control in pot and bedding crops and establishing blueprints for individual crops.

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Appendix I - Specification for irrigation on concrete floors

1. Dynamic loading for pot plant growing, an auction trolley with total load of 4.5 km (450 kg). Depth of concrete is usually 100 mm decreasing to 90 mm. The reinforcement consists of structural steel mats of 6 mm diameter mesh, width 150-200 mm.

2. Distribution pipe for watering and heating must not form an obstacle to transport and take up some of the room intended for plants.

3. Uniform heat output to give uniform plant growth, with 3% maximum difference in temperature.

4. Maximum water flow temperature 50°C.

5. Heat output must be capable of being matched to the plant needs and there must be a safety device to prevent too high a root temperature. The heating coil should be either 16 mm or 20 mm diameter. With 75 m plus coil, 20-25 mm pipe should be used and separation between lengths should be no more than 25 cm. This ensures that the temperature gradients are no more than 2°C. All piping should be anchored to the mesh reinforcement.

6. The water supply to a floor must be as uniform as possible with a maximum difference in depth for immersion of up to 10 mm.

7. After watering, no pools must remain on the floor.

8. Watering pipes must not become blocked.

9. Water absorption by the floor must be as low as possible, because of the possibility of nutrient solution attacking the concrete. A pH of 5.5-6 is common and sometimes lower.

10. A low water absorption is also desirable to prevent too much evaporation which costs energy and leads to high humidity in and around the crop as well as in the glasshouse.

11. The floor must be easy to clean after use.

12. The concrete must be durable and require little maintenance.

Appendix II - Stage 1 irrigation test results

Nursery	System	Media	Area tested (m^2)	No. pots	Spacing /m^2	Quantity water applied (l)	Weight before irrig (g)	Weight after irrig (g)	Water uptake per plant (ml)	Quantity water applied/plant (ml)	Recirculated water/plant (ml)	Unused water /plant (ml)
Ebb A	Ebb/flood benches	Bulrush Poinsettia mix with extra perlite	7.02	90	13	160	463	545	82	1778	1696	0
Ebb B	Ebb/flood bench	Lithuanian + Bulrush mix	6.92	105	15	142.4	411	536	125	1356	1231	0
Ebb C	Ebb/flood bench	Klausmann	10	200	20	231	513	652	139	1155	1016	0
Ebb/cap D	Cap-mat on bench		24.48	300	12	605	442	582	140	2017	1877	0
Cap A1	Cap-mat on floor	Own mix Shamrock/perlite	134.75	1875	14	151.6	547	584	37	81	0	44
Cap A2	Cap-mat on bench	Own mix Shamrock/perlite	8.85	95	11	24	528	606	78	253	0	175
Cap B1	Cap-mat on bench	Sinclair Poinsettia mix	120	1848	15	321.6	537	568	31	174	0	143
Cap B2	Cap-mat on floor	Sinclair Poinsettia mix	929.6	18788	20	11827.2	353	425	72	630	0	558
Cap C	Drip hose on matting	Bulrush Poinsettia mix	64	528	8	88.8	510	539	29	168	0	139
Cap D	Tape on saucers		88.94	756	9	194.6	574	615	41	257	0	216
Cap E	Gantry on cap	Bulrush	54	540	10	253	501	583	82	469	0	54
Tric A1	Trickle	Peat/perlite	272	3000	11	603	544	650	106	201	0	95
Tric A2	Trickle	Peat/perlite	272	3000	11	570	465	635	170	190	0	20
Tric B	Trickle		441	4410	10	671.2	514	614	100	152	0	52
Tric C	Trickle	Levington MC2 + 20%Coarse	2500	10000	4	800	575	633	58	80	0	22
Trough A	Trough track	Sinclair+perlite	58.8	544	9	926.5	373	591	218	1703	0	1485
Hand A	Hand-watering	Sinclair Poinsettia mix	31.7	330	10	114	516	641	125	345	0	220
Hand B	Hand-watering	Bulrush Poinsettia	32	604	19	140	466	679	213	232	0	19
Hand C	Hand-watering	Bulrush Poinsettia mix	10	70	7	54.89	643	814	171	784	0	613
Hand D	Hand-watering onto saucers		42.86	450	10	253.7	525	697	172	564	0	392
Spray A	Overhead sprayline boom	Bulrush	6	117	20	33.696	352	481	129	288	0	159

Appendix III - Water Quality for Stage 1 Nurseries (Untreated water)

Nursery		pH	EC	NH4	NO3	P	K	Ca	Mg	Na	Cl	SO4	Fe	Mn	Cu	Zn	B	Alk	KCa	KMg	KN
	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	Mg/l	mg/l			
Trough A	28/09/99	7.4	367	< 1	5	< 1	2	56.4	6	17	31	18	< 0.10	0.01	< 0.01	0.02	< 0.10	102	0	0.4	0.5
Ebb A	27/09/99	7.7	640	< 1	7	< 1	4	136	4	11	35	< 10	< 0.10	< 0.01	0.01	0.01	< 0.10	337	0	1	0.5
Ebb B	28/09/99	6.9	567	< 1	49	< 1	1	104	2	12	24	< 10	< 0.10	< 0.01	< 0.01	0.01	< 0.10	68	0	0.6	0
Ebb C	30/11/99	7.3	1010	<1	54	<1	22	114	24	41	72	48	<0.10	0.02	<0.01	0.01	0.1		0.2	0.9	0.4
Cap A1	24/09/99	8	460	< 1	< 1	< 1	< 1	83.5	6	11	24	28	< 0.10	< 0.01	< 0.01	0.02	< 0.10	166	0	0.1	< 1.0
Cap A2	24/09/99	8	580	< 1	< 1	< 1	< 1	113	8	13	29	37	< 0.10	0.04	< 0.01	1.26	< 0.10	229	0	0.1	< 1.0
Cap B	24/09/99	8	530	< 1	3	< 1	3	90	6	17	37	19	< 0.10	< 0.01	< 0.01	0.11	< 0.10	200	0	0.5	1
Cap C	23/09/99	7.9	540	< 1	8	< 1	< 1	108	6	11	27	13	< 0.10	< 0.01	0.04	0.1	< 0.10	239	0	< 0.0	< 0.1
Ebb/cap D - borehole	09/12/99	7	670	<1	36	<1	2	85.5	17	27	42	17	<0.10	0.01	<0.01	0.16	<0.10	146	0	0.1	0.1
Ebb/cap D - mains	09/12/99	6.8	480	<1	10	<1	2	55.8	14	26	49	19	<0.10	0.02	0.22	0.3	0.12	127	0	0.1	0.1
Tric A	23/09/99	8	700	< 1	5	< 1	6	70.8	15	65	89	31	< 0.10	< 0.01	< 0.01	0.03	0.17	176	0.1	0.4	1.4
Tric B	05/10/99	7.6	250	< 1	< 1	< 1	1	21.2	4	26	11	21	< 0.10	0.02	0.01	< 0.01	< 0.10	73	0.1	0.2	1
Tric C	05/10/99	7.8	470	< 1	< 1	< 1	4	74.5	16	16	14	< 10	0.2	0.55	< 0.01	< 0.01	< 0.10	298	0.1	0.3	4.4
Hand A	28/09/99	7.7	863	< 1	10	< 1	4	152	9	43	76	33	< 0.10	0.01	< 0.01	0.15	< 0.10	317	0	0.4	0.4
Hand B	03/09/99	7.5	440	< 1	22	< 1	6	64.1	8	17	31	23	2.28	< 0.01	< 0.01	0.01	< 0.10	146	0.1	0.7	0.3
Hand C	23/09/99	7.9	680	< 1	10	3	12	92.8	10	46	57	24	< 0.10	< 0.01	0.02	0.02	0.3	224	0.1	1.2	1.2

Appendix IV - Water Quality in Stage 1 Nurseries (Irrigation water - including feed where added)

Nursery		pH	EC	NH4	NO3	P	K	Ca	Mg	Na	Cl	SO4	Fe	Mn	Cu	Zn	B	Alk	KCa	KMg	KN
	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	Mg/l	mg/l			
Trough A	28/09/99	6.9	1770	70	173	25	169	83.7	20	30	31	22	1.54	0.75	0.74	0.35	0.39	107	2	8.6	0.7
Ebb A	27/09/99	7.1	1520	8	142	24	144	191	19	17	39	11	0.67	0.3	0.33	0.25	0.3	229	0.8	7.5	1
Ebb B	28/09/99	6	1750	16	185	35	217	115	37	54	26	29	6.9	3.41	3.14	1.31	1.51	39	1.9	5.9	1.1
Ebb C	05/10/99	6.1	2480	80	173	77	333	118	53	49	83	126	1.05	0.61	0.18	0.64	0.26	68	2.8	6.3	1.3
Cap A1	24/09/99	7	1720	9	168	35	151	241	8	13	29	32	< 0.10	< 0.01	< 0.01	0.12	< 0.10	137	0.6	17.9	0.9
Cap B	24/09/99	6.7	1170	12	137	17	185	102	1	6	10	< 10	0.23	0.06	0.12	0.13	< 0.10	44	1.8	231	1.2
Cap C	23/09/99	6.7	1840	13	160	40	211	212	11	15	30	32	0.54	3.49	0.37	0.4	0.23	185	1	18.5	1.2
Ebb/cap D	08/10/99	6.9	1740	35	164	49	178	99	49	35	41	18	1.31	0.67	0.7	0.79	0.39	142	1.8	3.6	0.9
Cap E	23/09/99	6.9	900	4	35	6	40	78.1	18	60	85	30	0.28	0.11	0.03	0.08	0.22	161	0.5	2.2	1
Tric A1 + feed	23/09/99	7.1	710	< 1	38	< 1	4	70.6	15	56	77	27	< 0.10	< 0.01	< 0.01	0.45	0.15	29	0.1	0.3	0.1
Tric A2 - feed	23/09/99	6.9	1270	10	77	24	150	69.1	21	58	80	37	< 0.10	0.04	0.02	0.06	0.16	93	2.2	7.2	1.7
Tric B	05/10/99	6.6	1280	77	111	19	119	23.2	13	24	10	30	1.64	0.05	0.01	0.05	0.44	54	5.2	8.9	0.6
Tric C + feed	05/10/99	5.2	1170	12	130	12	82	108	27	16	14	< 10	0.75	1.23	0.08	0.27	0.16	29	0.8	3.1	0.6
Tric C - feed	05/10/99	5.8	690	1	64	4	12	87.7	19	16	14	< 10	0.1	1.26	0.02	0.1	< 0.10	49	0.1	0.7	0.2
Hand A	28/09/99	7.3	1670	11	75	40	242	151	22	44	78	57	< 0.10	0.05	0.02	0.06	< 0.10	312	1.6	10.8	2.8
Hand B	27/09/99	6.9	2110	112	150	63	148	71	47	42	31	83	4.01	1.6	1.52	0.63	0.9	181	2.1	3.2	0.6
Hand C	23/09/99	7	1960	11	189	36	173	234	20	61	64	31	2.6	1.23	1	0.42	0.86	185	0.7	8.7	0.9

Appendix V - Water Quality of Nurseries in Stage 1 (Run-off water)

Nursery		pH	EC	NH4	NO3	P	K	Ca	Mg	Na	Cl	SO4	Fe	Mn	Cu	Zn	B	Alk	KCa	KMg	KN
	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	Mg/l	mg/l			
Trough A	28/09/99	6.8	2280	81	232	37	236	77.2	27	35	31	24	2.21	0.84	1.09	0.47	0.58	112	3.1	8.9	0.8
Ebb B	28/09/99	6.1	1720	14	180	34	210	113	36	53	26	29	6.7	3.33	3.04	1.26	1.48	45	1.9	5.9	1.1
Ebb C	05/10/99	5.9	2470	67	176	77	332	119	53	49	83	126	1.05	0.6	0.18	0.64	0.26	54	2.8	6.3	1.4
Cap A	24/09/99	7.7	730	2	18	8	29	111	16	16	40	45	< 0.10	< 0.01	< 0.01	0.07	< 0.10	181	0.3	1.8	1.4
Cap B	24/09/99	6.6	2050	21	234	26	211	139	7	12	20	14	3.61	0.03	0.01	0.47	< 0.10	54	1.5	31.6	0.8
Cap C	23/09/99	7.4	1650	< 1	131	2	46	200	67	44	93	33	< 0.10	0.04	0.02	0.08	< 0.10		0.2	0.7	0.4
Ebb/cap D	08/10/99	7	1770	30	167	53	196	113	50	39	43	20	1.47	0.82	0.86	0.97	0.44	142	1.7	3.9	1
Hand A	28/09/99	7.6	1610	11	67	32	210	156	21	49	87	57	< 0.10	0.03	0.02	0.1	< 0.10	332	1.4	10	2.7
Hand B	27/09/99	7.2	2550	139	181	68	183	102	68	55	49	111	5.59	1.92	1.62	0.81	0.91	239	1.8	2.7	0.6
Hand C	23/09/99	6.4	2990	13	332	43	248	254	88	126	129	66	4.05	0.48	0.72	0.87	0.96	73	1	2.8	0.7

Appendix VI - Average Particle Size Analysis results (% of particles) and AFPs for Stage 1 nurseries tested

Nursery	13.2mm	9.5mm	6.7mm	4.8mm	3.4mm	2.0mm	1.0mm	0.5mm	0.1mm	Pan	AFP (%)
Cap D/ Hand D	19.1	20.8	11.4	11.4	8.6	10.1	7.9	6.2	3.4	1.2	7.6%
Hand C	11.2	11.6	8.2	9.2	7.8	9.8	10.7	12.8	15.9	2.7	5.5%
Tric C	11.2	11.6	8.2	9.2	7.8	9.8	10.7	12.8	15.9	2.7	4.0%
Cap B1/B2	27.2	19.2	2.3	1.1	6.7	8.0	11.6	15.1	8.6	0.2	5.5%
Cap C	11.4	21.8	12.4	11.9	9.3	9.4	8.3	7.6	7.0	0.9	3.4%
Ebb A	7.7	11.5	14.0	13.6	11.0	11.0	9.9	9.0	10.1	2.1	4.7%
Trough A	19.8	14.7	8.8	8.5	9.7	10.5	14.4	8.9	4.4	0.4	10.3%
Ebb B	13.2	12.9	5.6	9.0	8.9	12.5	16.8	11.9	9.3	0.7	7.9%
Hand A	21.0	20.5	11.0	9.4	13.2	9.9	6.7	5.7	2.4	0.2	9.0%
Cap A1/A2	13.1	22.8	10.9	10.9	10.1	10.5	8.8	8.2	3.8	0.9	3.4%

Average Particle Size Analysis results (% of particles) and AFPs for Stage 2 nurseries tested

Nursery	Samples taken	13.2mm	9.5mm	6.7mm	4.8mm	3.4mm	2.0mm	1.0mm	0.5mm	0.1mm	Pan	AFP (%)
A	Start	26.8	21.4	10.0	9.9	9.5	8.7	5.4	4.8	3.3	0.3	7.2%
	End	20.9	14.5	9.5	9.2	11.6	12.3	10.9	7.3	3.7	0.2	10.0
B	Start	12.7	13.4	9.8	10.8	9.4	11.4	10.4	9.3	10.1	2.8	4.5%
	End	13.8	16.5	12.8	9.9	11.2	12.2	9.2	7.9	5.4	1.2	8.1
C	Start	8.1	13.9	13.1	14.0	10.6	9.7	9.7	9.1	10.4	1.3	8.7%
	End	13.7	21.7	15.8	8.6	6.7	7.0	7.2	8.4	9.5	1.4	9.9
D	Start	10.8	13.3	11.7	14.4	9.6	10.5	10.1	9.1	7.9	2.6	7.9%
	End	12.9	16.3	9.2	11.1	9.6	10.6	9.8	9.3	9.5	1.8	9.8

Note: 'Start' refers to samples taken soon after potting (August) and 'End' refers to samples taken at point of sale (December).

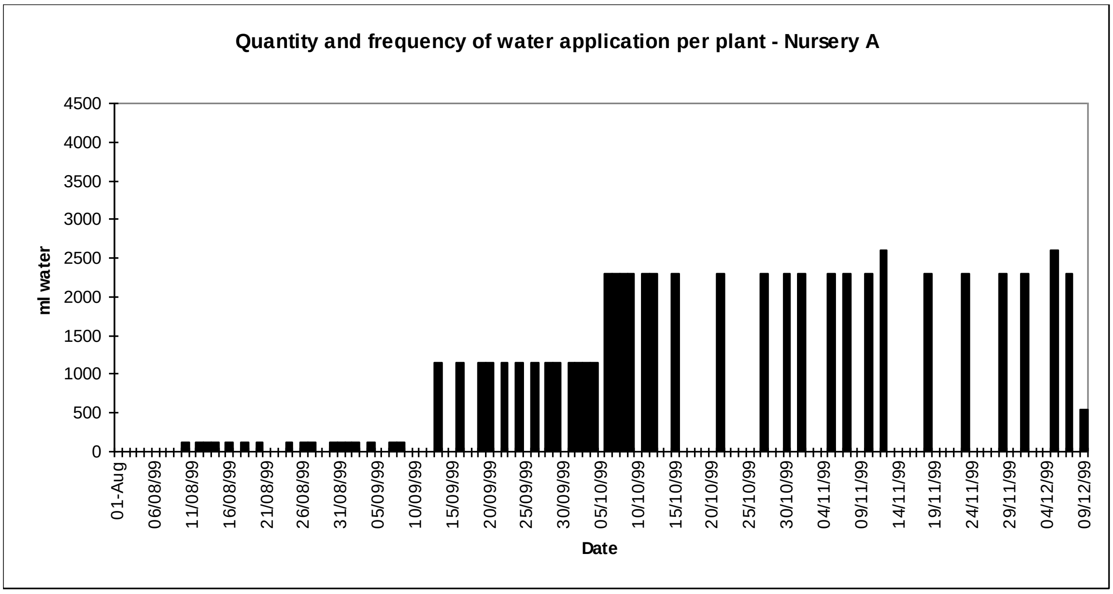
Appendix VII - Quantity of water applied in each nursery to each plant in Stage 2

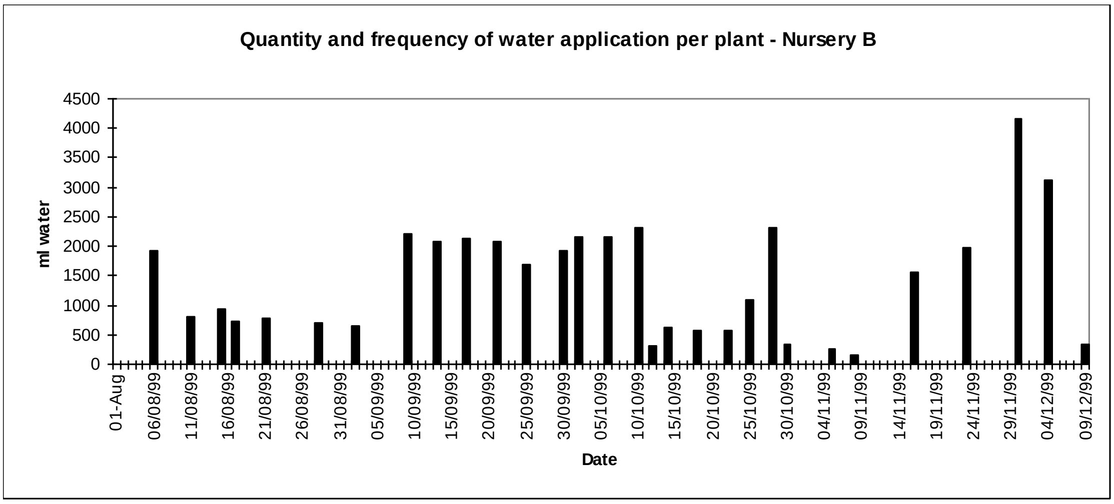
Date	Cumulative water application per plant (ml)			
	A	B	C	D
01-Aug				
02-Aug				
03-Aug				300
04/08/99				600
05/08/99				650
06/08/99		1929		700
07/08/99		1929		710
08/08/99		1929		720
09/08/99		1929		720
10/08/99	114	1929		720
11/08/99	114	2748		720
12/08/99	227	2748	27	730
13/08/99	341	2748	27	750
14/08/99	455	2748	27	750
15/08/99	455	3681	76	800
16/08/99	568	3681	113	810
17/08/99	568	4403	113	820
18/08/99	682	4403	113	830
19/08/99	682	4403	169	850
20/08/99	795	4403	210	900
21/08/99	795	5197	210	930
22/08/99	795	5197	262	960
23/08/99	795	5197	262	1000
24/08/99	909	5197	295	1170
25/08/99	909	5197	349	1200
26/08/99	1023	5197	349	1250
27/08/99	1136	5197	349	1300
28/08/99	1136	5892	349	1350
29/08/99	1136	5892	383	1400
30/08/99	1250	5892	383	1450
31/08/99	1364	5892	383	1550
01/09/99	1477	5892	432	1580
02/09/99	1591	6544	487	1600
03/09/99	1591	6544	487	1630
04/09/99	1705	6544	526	1650
05/09/99	1705	6544	526	1680
06/09/99	1705	6544	573	1700
07/09/99	1818	6544	573	1720
08/09/99	1932	6544	632	1930
09/09/99	1932	8748	680	2000
10/09/99	1932	8748	736	2100
11/09/99	1932	8748	736	2150
12/09/99	1932	8748	736	2210
13/09/99	3082	10831	736	2260
14/09/99	3082	10831	798	2320
15/09/99	3082	10831	849	2320

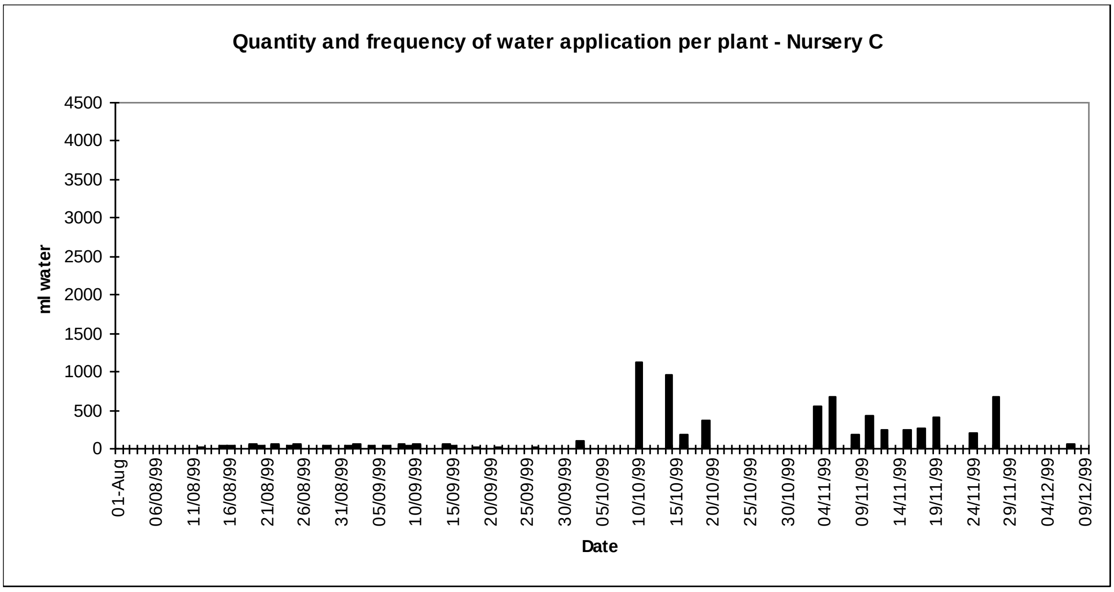
Date	Cumulative water application per plant (ml)			
	A	B	C	D
16/09/99	4232	10831	849	2320
17/09/99	4232	12958	849	2672
18/09/99	4232	12958	872	2672
19/09/99	5382	12958	872	2811
20/09/99	6532	12958	872	2811
21/09/99	6532	15041	887	2924
22/09/99	7682	15041	887	2924
23/09/99	7682	15041	887	3156
24/09/99	8832	15041	887	3354
25/09/99	8832	16741	887	3354
26/09/99	9982	16741	917	3569
27/09/99	9982	16741	917	3569
28/09/99	11132	16741	917	3569
29/09/99	12282	16741	917	3569
30/09/99	12282	18674	917	3569
01/10/99	13432	18674	917	3569
02/10/99	14582	20838	1014	3569
03/10/99	15732	20838	1014	3569
04/10/99	16882	20838	1014	3752
05/10/99	16882	20838	1014	3851
06/10/99	19182	22984	1014	3851
07/10/99	21482	22984	1014	4397
08/10/99	23782	22984	1014	4397
09/10/99	26082	22984	1014	4397
10/10/99	26082	25294	2132	4397
11/10/99	28382	25294	2132	4397
12/10/99	30682	25614	2132	4993
13/10/99	30682	25614	2132	4993
14/10/99	30682	26238	3095	4993
15/10/99	32982	26238	3095	4993
16/10/99	32982	26238	3282	5076
17/10/99	32982	26238	3282	5076
18/10/99	32982	26801	3282	5076
19/10/99	32982	26801	3653	5159
20/10/99	32982	26801	3653	5159
21/10/99	35282	26801	3653	5159
22/10/99	35282	27378	3653	5159
23/10/99	35282	27378	3653	5159
24/10/99	35282	27378	3653	5159
25/10/99	35282	28481	3653	5391
26/10/99	35282	28481	3653	5391
27/10/99	37582	28481	3653	5391
28/10/99	37582	30804	3653	5391
29/10/99	37582	30804	3653	5523
30/10/99	39882	31154	3653	5523
31/10/99	39882	31154	3653	5523

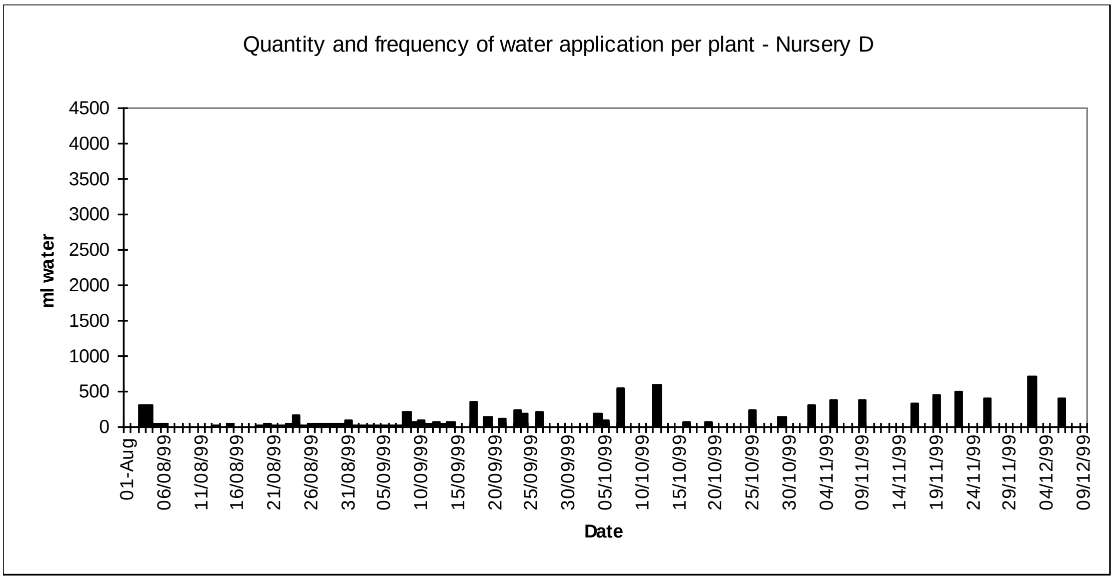
Date	Cumulative water application per plant (ml)			
	A	B	C	D
01/11/99	42182	31154	3653	5523
02/11/99	42182	31154	3653	5821
03/11/99	42182	31154	4195	5821
04/11/99	42182	31154	4195	5821
05/11/99	44482	31414	4875	6193
06/11/99	44482	31414	4875	6193
07/11/99	46782	31414	4875	6193
08/11/99	46782	31558	5065	6193
09/11/99	46782	31558	5065	6565
10/11/99	49082	31558	5493	6565
11/11/99	49082	31558	5493	6565
12/11/99	51682	31558	5743	6565
13/11/99	51682	31558	5743	6565
14/11/99	51682	31558	5743	6565
15/11/99	51682	31558	5991	6565
16/11/99	51682	33128	5991	6896
17/11/99	51682	33128	6249	6896
18/11/99	53982	33128	6249	6896
19/11/99	53982	33128	6665	7350
20/11/99	53982	33128	6665	7350
21/11/99	53982	33128	6665	7350
22/11/99	53982	33128	6665	7846
23/11/99	56282	35094	6665	7846
24/11/99	56282	35094	6871	7846
25/11/99	56282	35094	6871	7846
26/11/99	56282	35094	6871	8259
27/11/99	56282	35094	7549	8259
28/11/99	58582	35094	7549	8259
29/11/99	58582	35094	7549	8259
30/11/99	58582	39248	7549	8259
01/12/99	60882	39248	7549	8259
02/12/99	60882	39248	7549	8962
03/12/99	60882	39248	7549	8962
04/12/99	60882	42371	7549	8962
05/12/99	63482	42371	7549	8962
06/12/99	63482	42371		9375
07/12/99	65782	42371		9375
08/12/99				9375

Appendix VIII - Profile of water use on each nursery








Quantity and frequency of water application per plant - Nursery D
ml water
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01-Aug
06/08/99
11/08/99
16/08/99
21/08/99
26/08/99
31/08/99
05/09/99
10/09/99
15/09/99
20/09/99
25/09/99
30/09/99
05/10/99
10/10/99
15/10/99
20/10/99
25/10/99
30/10/99
04/11/99
09/11/99
14/11/99
19/11/99
24/11/99
29/11/99
04/12/99
09/12/99
Date

Appendix IX - Light Levels Reaching Stage 2 Nurseries (W/m^2)

	Nursery A				Nursery B				
Day	Aug	Sep	Oct	Nov	Aug	Sep	Oct	Nov	Dec
1	6080	4237	1006	484	7017	4540	2077	362	957
2	5944	4693	2969	1818	4451	5344	3516	1863	1335
3	5363	5290	2644	823	4720	5604	3340	1533	480
4	4868	4342	2966	1332	3324	5347	3827	1679	1344
5	5335	4670	3567	272	7045	5067	3754	260	1250
6	6330	3836	3330	1774	3274	5166	3555	1840	444
7	1145	3253	1131	1737	6489	4052	1693	1315	869
8	1270	3489	1829	1059	4796	4394	1380	754	326
9	795	4323	1184	1062	3765	5185	1519	1838	792
10	1523	2599	2099	1101	2481	4468	1457	588	1055
11	4042	3934	2699	559	3829	4293	2939	1744	183
12	3033	2627	2480	170	6568	4451	3527	1567	863
13	2424	1846	2524	659	3989	3071	3307	1962	357
14	1426	681	2221	548	4174	1003	2988	738	1260
15	4392	878	806	887	4555	2671	2770	1890	1278
16	3472	1715	1929	1140	4901	1988	2950	1723	1117
17	3127	3989	2544	1156	1901	4023	3097	1807	195
18	2866	2886	2819	1462	5078	1706	3303	1360	341
19	2513	1309	2416	792	5710	2263	2969	1507	1366
20	2741	1068	512	648	5973	1631	425	1421	1104
21	3519	1940	181	876	5593	4061	449	811	124
22	4804	2321	948	259	4814	1913	914	446	160
23	4392	2213	1357	678	4976	2905	1909	778	1095
24	2199	1198	664	659	1179	2733	1068	1033	220
25	2694	2382	1882	945	2202	2956	2922	652	550
26	3700	2282	1601	945	5712	3842	2342	849	543
27	3500	2027	1915	787	4774	2518	2438	1360	343
28	4912	2257	1690	1095	5989	2630	1356	921	1067
29	4598	1487	1337	728	5099	1794	787	147	1216
30	4551	1977	1095	153	5283	2907	1094	902	181
31	3367		1988		3934		2329		399

	Nursery C					Nursery D				
Day	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	5587	5007	1276	-	988	5262	3275	701	408	866
2	4797	5095	3113	2080	886	4602	3350	2471	1787	366
3	1554	4636	2061	1392	614	1786	3372	1980	1020	520
4	4472	4916	3568	1119	1095	4594	4603	3295	427	447
5	5887	5056	3276	339	916	3106	4865	2994	291	491
6	3732	4298	2967	1556	363	4803	4462	2990	1814	90
7	1707	3479	915	1076	561	1449	3567	1469	557	640
8	628	2551	1335	637	274	2177	2671	875	485	275
9	2852	4768	1766	1526	887	1271	4831	696	1384	156
10	1890	4891	1202	555	763	2510	4940	968	849	529
11	4187	3175	3276	647	242	3834	1622	2208	318	112
12	2570	3356	2410	1231	197	3389	3867	1990	505	308
13	2871	3393	2776	564	155	2026	3149	2696	284	260
14	4634	2052	2667	499	1065	2920	4332	662	354	710
15	5068	681	1943	1257	530	3345	3144	1184	544	711
16	-	2911	1727	912	756	3546	1876	2020	789	455
17	-	4417	2809	1498	235	2172	3702	2677	1361	387
18	-	1784	2965	1462	661	3319	2343	2850	781	519
19	1866	1002	2761	1274	1141	1828	658	2527	1149	949
20	4425	1583	1081	1213	804	3937	1988	1308	692	594
21	6316	2670	429	608	141	6213	3813	420	521	219
22	5091	1582	1327	434	100	6048	2516	1714	730	44
23	4643	2779	1261	955	980	5289	2384	1418	570	653
24	1860	2249	562	653	360	2665	2744	373	255	457
25	1867	2019	1494	1116	623	1546	1990	1354	783	297
26	3338	3053	1077	334	506	2977	1652	1147	145	427
27	4222	1596	1805	967	510	4007	1392	1178	804	322
28	5398	-	816	674	560	3857	1904	1763	230	774
29	4238	-	509	249	897	2854	1120	1053	723	922
30	4799	-	-	530	180	2221	1403	603	349	289
31	2821		-		267	1586		1266		317

Appendix X - Water Quality for Stage 2 Nurseries - Nursery A

Nursery		**pH**	**EC**	**NH4**	**NO3**	**P**	**K**	**Ca**	**Mg**	**Na**	**Cl**	**SO4**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Alk**	**KCa**	**KMg**	**KN**
Week no.	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	Mg/l	mg/l	mg/l	mg/l			
A - Irrigation																					
w34	03/09/99	7.3	930	< 1	45	< 1	18	114	23	41	73	47	< 0.10	< 0.01	< 0.01	0.02	0.1	98	0.2	0.8	0.4
w36	01/10/99	4.8	2470	45	173	61	342	124	54	51	92	138	1.49	0.49	0.16	0.94	0.24	15	2.8	6.3	1.6
w38	05/10/99	6.1	2480	80	173	77	333	118	53	49	83	126	1.05	0.61	0.18	0.64	0.26	68	2.8	6.3	1.3
w40	09/11/99	4.9	1830	44	136	42	180	117	38	47	81	91	0.61	0.32	0.09	0.53	0.19	10	1.5	4.7	1
w42																					
w44	09/11/99	6.5	1870	52	141	42	168	116	38	46	82	81	0.65	0.34	0.1	0.6	0.19	44	1.5	4.4	0.9
w46	23/11/99	6.2	1650	29	118	32	146	123	37	47	88	80	0.45	0.28	0.08	0.81	0.18	59	1.2	3.9	1
A - Run-off																					
w34	03/09/99	7.5	1390	2	71	3	41	152	38	65	109	72	< 0.10	< 0.01	< 0.01	0.15	0.13	107	0.3	1.1	0.6
w36	01/10/99	4.9	2490	50	175	63	348	126	55	52	93	141	1.5	0.49	0.17	0.96	0.24	15	2.8	6.3	1.6
w38	05/10/99	5.9	2470	67	176	77	332	119	53	49	83	126	1.05	0.6	0.18	0.64	0.26	54	2.8	6.3	1.4
w40	09/11/99	5	1850	42	137	41	186	121	40	48	85	94	0.61	0.31	0.1	0.62	0.2	5	1.5	4.7	1
w42																					
w44	09/11/99	6.5	1940	51	141	43	170	116	38	46	83	81	0.67	0.33	0.1	0.58	0.19	44	1.5	4.5	0.9
w46	23/11/99	6.5	1350	8	86	15	84	130	37	52	94	77	0.25	0.05	0.04	0.42	0.14	68	0.7	2.3	0.9

Appendix XI - Water Quality for Stage 2 Nurseries - Nursery B

Nursery		**pH**	**EC**	**NH4**	**NO3**	**P**	**K**	**Ca**	**Mg**	**Na**	**Cl**	**SO4**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Alk**	**KCa**	**KMg**	**KN**
Week no.	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l			
B - Irrigation																					
w34	25/08/99	7.2	830	2	68	< 1	3	156	3	16	29	< 10	< 0.10	< 0.01	< 0.01	0.01	< 0.10	259	0	1.2	0
w36	13/09/99	7.3	1380	10	124	18	128	166	18	24	30	12	1.38	0.41	0.52	0.38	0.32	239	0.8	7.1	1
w38																					
w40	08/10/99	6.9	1740	35	164	49	178	99	49	35	41	18	1.31	0.67	0.7	0.79	0.39	142	1.8	3.6	0.9
w42	25/10/99	6.8	1460	10	128	39	156	98.5	27	37	53	23	1.52	0.71	0.75	0.88	0.4	112	1.6	5.9	1.1
w44	10/11/99	7	1420	9	138	23	174	121	30	33	45	18	2.15	0.27	0.3	0.56	0.21	117	1.4	5.8	1.2
w46	18/11/99	6.9	1210	3	114	10	85	125	32	31	45	18	0.76	0.19	0.32	0.58	0.25	117	0.7	2.7	0.7
B - Run-off																					
w34																					
w36	13/09/99	7.1	1400	9	124	17	129	168	18	25	31	12	1.36	0.25	0.52	0.43	0.3	244	0.8	7.3	1
w38																					
w40	08/10/99	7	1770	30	167	53	196	113	50	39	43	20	1.47	0.82	0.86	0.97	0.44	142	1.7	3.9	1
w42	25/10/99	6.9	1510	27	137	42	159	105	33	39	48	24	1.57	0.66	0.77	1.22	0.41	98	1.5	4.9	1
w44	10/11/99	6.9	1530	8	141	26	188	123	33	35	47	20	2.32	0.22	0.3	0.62	0.24	112	1.5	5.7	1.3
w46	18/11/99	7.1	1380	4	133	13	105	137	36	36	52	21	0.81	0.07	0.36	0.45	0.26	122	0.8	2.9	0.8

Appendix XII - Water Quality for Stage 2 Nurseries - Nursery C

Nursery		**pH**	**EC**	**NH4**	**NO3**	**P**	**K**	**Ca**	**Mg**	**Na**	**Cl**	**SO4**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Alk**	**KCa**	**KMg**	**KN**
Week no.	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l			
C - Irrigation																					
w34																					
w36	09/09/99	7.2	1130	8	75	12	84	92.1	22	55	78	28	0.67	0.27	0.07	0.18	0.25	156	0.9	3.8	1
w38	23/09/99	6.9	900	4	35	6	40	78.1	18	60	85	30	0.28	0.11	0.03	0.08	0.22	161	0.5	2.2	1
w40	07/10/99	7.8	1370	11	155	< 1	4	235	5	18	20	15	< 0.10	0.02	< 0.01	0.02	< 0.10	93	0	0.9	0
w42	25/10/99	6.6	1530	11	152	29	199	104	28	28	38	18	1.59	0.71	0.15	0.44	0.28	78	1.9	7.1	1.2
w44	08/11/99	6.5	1690	9	201	21	171	180	21	18	23	13	1.02	0.49	0.11	0.26	0.2	78	1	8.2	0.8
w46	18/11/99	6.6	1730	10	199	23	186	190	21	22	35	14	1.15	0.67	0.13	0.31	0.24	93	1	8.8	0.9
C - Run-off																					
w34																					
w36																					
w38																					
w40	07/10/99	7.7	1680	16	196	< 1	16	267	17	34	36	23	< 0.10	0.08	0.01	0.21	< 0.10	98	0.1	1	0.1
w42																					
w44																					
w46																					

Appendix XIII - Water Quality for Stage 2 Nurseries - Nursery D

Nursery		**pH**	**EC**	**NH4**	**NO3**	**P**	**K**	**Ca**	**Mg**	**Na**	**Cl**	**SO4**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Alk**	**KCa**	**KMg**	**KN**
Week no.	Logdate		æS/cm 20øC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l			
D - Irrigation																					
w34	03/09/99	7.1	1910	12	145	29	180	73	32	45	32	61	4.15	1.84	1.71	0.66	0.91	181	2.5	5.7	1.2
w36	09/09/99	7	1780	80	137	27	148	70.2	37	38	32	66	4.37	1.56	1.43	0.55	0.76	181	2.1	4	0.7
w38	27/09/99	6.9	2110	112	150	63	148	71	47	42	31	83	4.01	1.6	1.52	0.63	0.9	181	2.1	3.2	0.6
w40	11/10/99	7.1	1160	45	73	19	85	62.2	23	29	32	38	2.23	0.76	0.79	0.32	0.46	171	1.4	3.7	0.7
w42	20/10/99	7.1	1390	55	19	28	118	63.6	25	35	7	37	3.75	1.23	1.09	0.45	0.72	137	1.9	4.7	1.6
w44	03/11/99	5.8	6600	11	773	221	529	66.2	202	51	42	35	5.26	1.5	1.71	0.58	1.12	98	8	2.6	0.7
w46	17/11/99	7	1330	47	104	43	159	65.2	27	41	36	30	4.24	1.46	1.37	0.53	0.74	171	2.4	5.9	1.1
D - Run-off																					
w34	03/09/99	6.4	2630	12	214	52	201	160	93	64	67	127	4.9	2.82	1.34	1.48	0.52	93	1.3	2.2	0.9
w36	09/09/99	6.2	3150	82	289	47	240	191	114	92	101	161	8.31	2.36	1.38	1.27	0.61	93	1.3	2.1	0.7
w38	27/09/99	7.2	2550	139	181	68	183	102	68	55	49	111	5.59	1.92	1.62	0.81	0.91	239	1.8	2.7	0.6
w40	11/10/99	6.9	1220	40	71	19	82	78	26	32	38	49	1.94	0.32	0.7	0.34	0.41	156	1	3.2	0.7
w42	20/10/99	6.4	2750	11	196	54	200	197	79	87	101	152	7	2.31	1.48	1.59	0.82	83	1	2.5	1
w44	03/11/99	5.6	9230	11	1200	265	619	276	377	105	89	132	16.6	2.43	2.09	1.15	1.28	156	2.2	1.6	0.5
w46																					
D - Untreated																					
w34	03/09/99	7.5	440	< 1	22	< 1	6	64.1	8	17	31	23	2.28	< 0.01	< 0.01	0.01	< 0.10	146	0.1	0.7	0.3

Appendix XIV - Nutrient content of tested plants in Stage 2 - Content of plugs at potting

Nursery	Plant number	Fresh weight (g)	Dry weight (g)	Oven dry matter % m/m	N %m/m	Ca %m/m	K%m/m	Mg %m/m	P %m/m
A	1	7.7	0.7	9.1	4.56	4.94	11.8	1.39	1.8
	2	5	0.5	10	3.62	1.45	2.44	0.38	0.5
	3	10.6	1.1	10.4	4	1.62	2.78	0.45	0.49
	4	6.4	0.6	9.4	4.39	1.54	2.69	0.45	0.55
	5	10.5	1.1	10.5	3.31	1.35	2.4	0.4	0.43
	6	6.4	0.7	10.9	3.83	1.28	2.09	0.36	0.45
	7	9.1	1	11	4.1	1.41	2.83	0.41	0.52
	8	7.5	0.6	8	4.13	1.36	3.01	0.36	0.5
	9	8.2	0.9	11	3.17	1.18	2.3	0.32	0.36
	10	6.9	0.8	11.6	4.39	1.36	2.8	0.39	0.5
	11	7.7	0.8	10.4	3.97	1.37	2.88	0.39	0.46
	12	4.3	0.5	11.6	4.09	1.19	2.54	0.39	0.47
	13	7.1	0.7	9.9	4.35	1.48	2.94	0.44	0.52
	14	6.9	0.8	11.6	4.52	1.46	2.96	0.41	0.54
	15	7.8	0.8	10.3	3.63	1.24	2.52	0.37	0.46
	16	6.5	0.6	9.2	4.51	1.22	2.68	0.43	0.52
	17	6	0.5	8.3	4.24	1.27	2.51	0.39	0.5
	18	8.5	1	11.8	3	1.41	2.33	0.38	0.38
	19	5.8	0.6	10.3	3.96	1.28	2.67	0.36	0.43
	20	9.6	0.9	9.4	3.6	1.43	2.26	0.37	0.43
Average		**7.39**	**0.76**	**10.28**	**3.99**	**1.56**	**3.14**	**0.45**	**0.55**
B	1	7.5	0.9	12	2.73	1.53	2.14	0.33	0.3
	2	6.9	0.9	13	2.92	1.24	1.76	0.25	0.28
	3	5.8	0.8	13.8	2.68	1.21	1.66	0.27	0.25
	4	8.3	0.9	10.8	2.66	1.28	1.88	0.24	0.27
	5	4.9	0.5	10.2	2.98	1.3	2.2	0.28	0.32
	6	4.5	0.5	11.1	2.57	0.95	1.9	0.22	0.31
	7	7.9	0.9	11.4	2.85	1.33	2.07	0.28	0.29
	8	4.6	0.4	8.7	3.64	1.32	2.24	0.27	0.3
	9	4.7	0.5	10.6	3.29	1.54	2.37	0.26	0.28
	10	4.4	0.4	9.1	3.56	1.6	2.63	0.3	0.32
	11	6.9	0.8	11.6	3	1.56	2.11	0.29	0.29
	12	7.4	0.8	10.8	2.71	1.31	1.86	0.31	0.29
	13	4.4	0.4	9.1	3.57	1.49	2.76	0.33	0.32
	14	5.8	0.7	12.1	2.83	1.31	2.39	0.28	0.29
	15	6.3	0.7	11.1	3.17	1.65	2.21	0.3	0.31
	16	6.6	0.7	10.6	2.89	1.37	1.93	0.27	0.28
	17	3.9	0.4	10.3	3.33	1.71	2.18	0.29	0.29
	18	5.8	0.7	12.1	3.12	1.36	1.94	0.29	0.3
	19	4	0.4	10	3.42	1.75	2.4	0.27	0.3
	20	5.8	0.6	10.3	2.73	1.43	2.05	0.27	0.28
Average		**5.82**	**0.65**	**10.94**	**3.03**	**1.41**	**2.13**	**0.28**	**0.29**

Nursery	Plant number	Fresh weight (g)	Dry weight (g)	Oven dry matter % m/m	N %m/m	Ca %m/m	K%m/m	Mg %m/m	P %m/m
C	1	3.2	0.5	15.6	3.11	1.22	2.4	0.31	0.36
	2	4.9	0.8	16.3	2.74	1.21	2.4	2.26	0.33
	3	4.1	0.5	12.2	2.96	1.11	2.04	0.25	0.33
	4	4.1	0.5	12.2	3.09	1.15	2.25	0.29	0.34
	5	4.6	0.6	13	3.09	1.03	2.57	0.28	0.4
	6	3.4	0.5	14.7	2.69	1.11	2.04	0.23	0.3
	7	4.7	0.8	17	2.68	1.18	2.13	0.24	0.33
	8	4.3	0.6	14	2.78	1.01	2.45	0.24	0.34
	9	4.7	0.7	14.9	2.69	1.08	2.2	0.23	0.28
	10	4.2	0.5	11.9	2.4	1.09	2.55	0.22	0.32
	11	3.2	0.5	15.6	1.94	1.58	2.82	0.21	0.24
	12	5	0.7	14	2.93	0.96	2.14	0.26	0.36
	13	2.9	0.2	6.9	2.98	0.9	2.4	0.26	0.37
	14	4.1	0.5	12.2	2.21	1.13	2.21	0.24	0.32
	15	5.2	0.5	9.6	2.52	1	2.12	0.26	0.3
	16	3.9	0.5	12.8	2.69	1.12	2.15	0.27	0.32
	17	3.9	0.4	10.3	2.92	1.05	2.49	0.28	0.38
	18	5.8	0.6	10.3	3.07	1.17	2.4	0.31	0.36
	19	4	0.4	10	2.92	1.08	2.42	0.3	0.44
	20	3	0.3	10	3.14	1.3	2.49	0.3	0.38
Average		**4.16**	**0.53**	**12.68**	**2.78**	**1.12**	**2.33**	**0.36**	**0.34**
D	1	4.2	0.5	11.9	3.6	0.87	3.06	0.28	0.5
	2	4.9	0.4	8.2	3.45	0.92	2.89	0.27	0.53
	3	4.5	0.5	11.1	3.13	0.93	2.85	0.27	0.49
	4	5.7	0.8	14	2.7	0.99	2.52	0.31	0.45
	5	4	0.5	12.5	2.9	0.93	2.49	0.28	0.38
	6	6.4	0.8	12.5	2.92	0.91	2.44	0.28	0.45
	7	4.9	0.5	10.2	2.87	0.86	2.69	0.26	0.46
	8	5.8	0.7	12.1	3.27	1.17	2.72	0.33	0.5
	9	5.2	0.6	11.5	2.86	1.02	2.88	0.3	0.53
	10	7.5	1	13.3	3.03	0.93	2.52	0.3	0.42
	11	3.2	0.4	12.5	3.41	0.85	2.97	0.26	0.45
	12	3.3	0.3	9.1		0.63	1.82	0.19	0.3
	13	5.9	0.7	11.9	3.92	0.94	2.61	0.28	0.44
	14	4.4	0.5	11.4	3.17	0.96	3.27	0.31	0.57
	15	6.8	0.9	13.2	3.02	0.8	2.5	0.27	0.42
	16	2.4	0.3	12.5	3.54	0.42	2.11	0.15	0.34
	17	5.4	0.6	11.1	3.18	0.84	2.47	0.26	0.38
	18	5.2	0.7	12.3	3.98	0.82	2.62	0.25	0.41
	19	2.9	0.3	10.3	3.06	0.76	2.46	0.23	0.42
	20	5.6	0.7	12.5	2.82	0.7	2.38	0.24	0.36
Average		**4.91**	**0.59**	**11.71**	**3.20**	**0.86**	**2.61**	**0.27**	**0.44**

Nutrient content of tested plants in Stage 2 - Content of plants at point of sale

Nursery	Plant number	Fresh weight (g)	Dry weight (g)	Oven dry matter % m/m	N %m/m	Ca %m/m	K%m/m	Mg %m/m	P %m/m
A	1	180.9	26.8	14.8	3.61	0.84	2.67	0.43	0.75
	2	227.5	33.9	14.9	3.43	0.82	3.02	0.43	0.65
	3	130.5	19.8	15.2	3.37	0.84	3.03	0.41	0.75
	4	161.6	24.4	15.1	3.66	0.86	3.19	0.45	0.73
	5	200.3	28.2	14.1	3.54	0.93	2.94	0.46	0.76
	6	190.4	26.4	13.9	3.51	0.93	3.08	0.45	0.8
	7	185.2	26.6	14.4	3.55	0.89	2.91	0.44	0.79
	8	155.1	23.3	15	3.57	0.93	2.88	0.45	0.78
	9	162.3	23.9	14.7	3.47	0.83	2.86	0.41	0.79
	10	154.6	21.7	14	3.72	0.86	3.01	0.45	0.83
Average		**174.84**	**25.50**	**14.61**	**3.54**	**0.87**	**2.96**	**0.44**	**0.76**
B	1	166.3	24.4	14.7	3.37	0.92	3.04	0.45	0.59
	2	159.6	23.6	14.8	3.6	0.94	2.68	0.44	0.58
	3	123.2	18	14.6	3.62	0.89	2.89	0.47	0.63
	4	200.2	26.9	14.8	3.46	0.86	2.82	0.45	0.6
	5	143.3	21.5	15	3.57	0.85	2.88	0.43	0.61
	6	228.1	35.9	15.7	3.37	0.76	2.75	0.39	0.43
	7	145.4	20.8	14.3	3.75	0.92	2.81	0.46	0.62
	8	221.6	33.4	15.1	3.24	0.91	3.02	0.44	0.59
	9	188.7	28.4	15.1	3.26	0.9	3	0.44	0.58
	10	228.2	33.4	14.6	3.45	0.86	2.93	0.42	0.56
Average		**180.46**	**26.63**	**14.87**	**3.47**	**0.88**	**2.88**	**0.44**	**0.58**
C	1	142.7	21.6	15.1	3.08	1.03	2.09	0.49	0.39
	2	111.6	16.8	15.1	3.34	1.07	2.2	0.48	0.46
	3	98.3	14.9	15.2	3.43	1.09	2.34	0.52	0.52
	4	65.1	9.4	14.4	3.69	1.02	2.45	0.5	0.61
	5	129	19.8	15.4	3.63	1	2.51	0.48	0.47
	6	104.2	16.2	15.6	3.33	0.89	2.17	0.45	0.39
	7	103.3	16	15.5	3.23	1	2.34	0.49	0.43
	8	136.6	21	15.4	3.25	0.93	2.2	0.5	0.4
	9	104.7	16.2	15.5	3.45	0.96	2.14	0.48	0.45
	10	74.4	11.7	15.7	3.44	1.05	2.29	0.48	0.49
Average		**106.99**	**16.36**	**15.29**	**3.39**	**1.00**	**2.27**	**0.49**	**0.46**
D	1	124	19	15.3	4.53	0.94	2.62	0.65	0.77
	2	129.7	19	14.7	4.48	0.97	2.46	0.65	0.74
	3	134.1	19.3	14.4	4.95	0.95	2.88	0.65	0.8
	4	125.8	18.4	14.6	4.52	0.97	2.79	0.65	0.8
	5	114.9	17.2	15	5.12	0.94	2.8	0.66	0.83
	6	113.6	16	14.1	4.67	0.95	2.45	0.64	0.73
	7	115.2	16.4	14.2	4.82	1.05	2.68	0.71	0.75
	8	158.7	24.1	15.2	4.41	1.02	2.65	0.63	0.69
	9	134.3	18.7	13.9	4.44	0.97	2.73	0.66	0.68
	10	159.6	22.7	14.2	4.16	1.06	2.49	0.56	0.69
Average		**130.99**	**19.08**	**14.56**	**4.61**	**0.98**	**2.66**	**0.65**	**0.75**

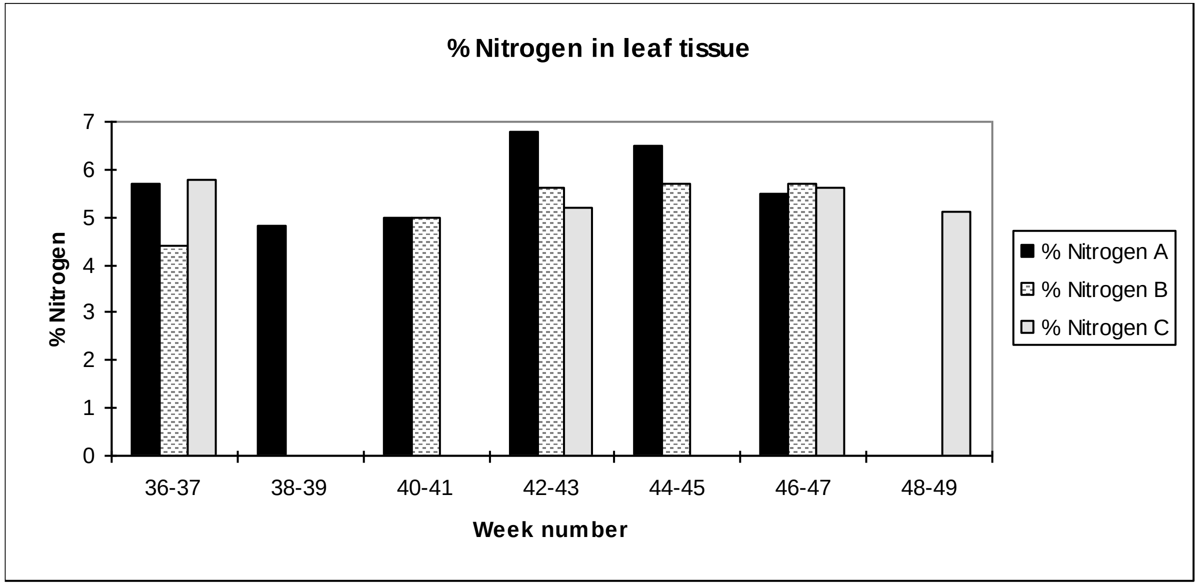
Appendix XV - Plant nutrient content and application of liquid feed

Nitrogen								
Nursery	Initial gN/pl	PoS gN/pl	Diff	gN/plant applied	gN/pl unused	g/pl loss from system	KgN unused/10,000 plants	Kg unused/10,000 in system
A	0.03	0.904	0.874	2.85	1.976	0	19.76	0
B	0.019	0.931	0.912	1.11	0.198	0	1.98	0
C	0.015	0.555	0.54	1	0.46	0.46	4.6	4.6
D	0.018	0.879	0.861	1.99	1.129	1.129	11.29	11.29
Potassium								
Nursery	Initial gK/pl	PoS gK/pl	Diff	gK/plant applied	gK/pl unused	g/pl loss from system	KgK unused/10,000 plants	Kg unused/10,000 in system
A	0.023	0.756	0.733	9.5	8.767	0	87.67	0
B	0.014	0.773	0.759	5.43	4.671	0	46.71	0
C	0.012	0.371	0.359	0.2	-0.159	-0.159	-1.59	-1.59
D	0.015	0.507	0.492	1.69	1.198	1.198	11.98	11.98
Phosphorus								
Nursery	Initial gP/pl	PoS gP/pl	Diff	gP/plant applied	gP/pl unused or recirculated	g/pl loss from system	KgP unused/10,000 plants	Kg unused/10,000 in system
A	0.004	0.194	0.19	2.35	2.16	0	21.6	0
B	0.002	0.156	0.154	1.08	0.926	0	9.26	0
C	0.002	0.075	0.073	0.29	0.217	0.217	2.17	2.17
D	0.003	0.143	0.14	0.38	0.24	0.24	2.4	2.4
Magnesium								
Nursery	Initial gMg/pl	PoS gMg/pl	Diff	gMg/plant applied	gMg/pl unused	g/pl loss from system	KgMg unused/10,000 plants	Kg unused/10,000 in system
A	0.003	0.112	0.109	0.92	0.811	0	8.11	0
B	0.002	0.118	0.116	0.5	0.384	0	3.84	0
C	0.002	0.08	0.078					
D	0.002	0.124	0.122	0.27	0.148	0.148	1.48	1.48

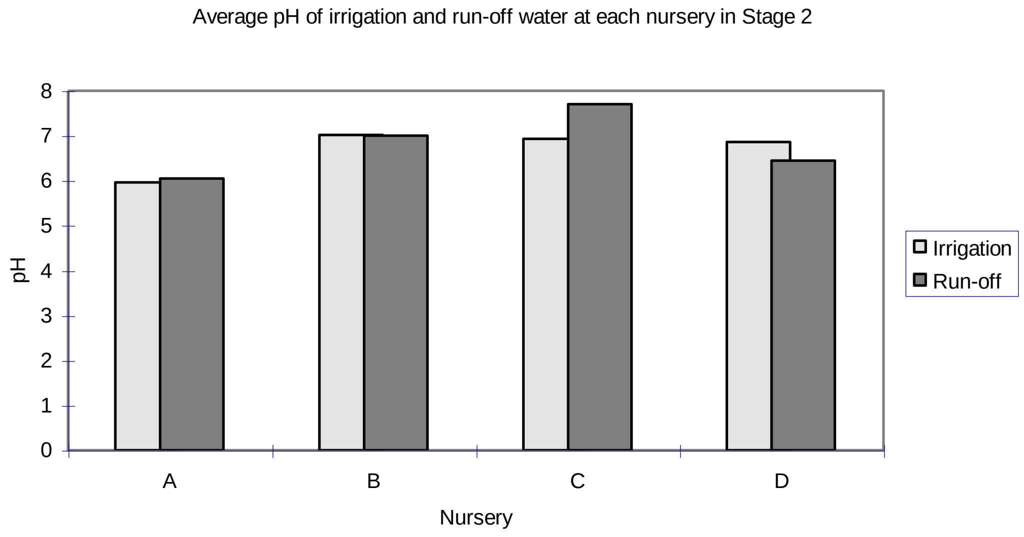
PoS g/pl = content of plant at Point of Sale
Initial g/pl = content of plant at potting
g/plant applied = quantity applied to each plant through the season (may have been applied more than once in recirculating systems (i.e. Nsy A and B)
g/plant unused = difference between quantity applied and quantity taken up by plant
g/plant loss from system = takes into account recirculation

Appendix XVI - Leaf tissue analysis

Nursery	Date	Cl %	N %	P %	K %	Mg %	Ca %	Mn mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg	B mg/kg
A	25/11/99	0.8	5.5	0.9	3.0	0.7	1.1	80.5	3.4	28.8	0.4	18.3
	11/11/99	0.7	6.5	0.8	2.4	0.6	0.9	65.5	4.4	28.2	0.1	16.0
		1.0	6.8	1.1	3.9	1.3	2.3	124.6	9.1	57.4	0.5	20.3
	09/10/99	1.2	5.0	0.9	2.9	1.2	2.6	125.5	3.6	49.3	0.5	16.9
	01/10/99	1.1	4.8	0.9	3.1	1.0	2.6	113.5	3.8	57.4	0.8	21.9
	07/09/99	1.1	5.7	0.8	2.3	0.9	2.3	107.9	2.9	60.4	0.5	15.9
B	22/11/99	0.3	5.7	0.7	2.5	0.6	0.9	56.1	5.4	54.6	5.5	20.2
	09/11/99	0.3	5.7	0.8	2.8	0.6	0.8	51.8	4.8	47.9	6.2	19.6
	27/10/99	0.4	5.6	0.7	3.5	0.6	0.9	54.3	3.6	36.6	7.3	17.5
	15/10/99	0.4	5.0	0.6	3.4	0.5	0.9	54.2	3.0	25.3	8.9	18.4
	16/09/99	0.0	4.4	0.8	3.2	0.6	1.3	112.1	4.2	38.1	0.8	18.0
C	07/12/99	0.6	5.1	0.5	2.3	0.8	1.3	115.6	2.5	25.0	0.7	20.6
	17/11/99	0.0	5.6	0.6	2.4	0.9	1.4	129.3	2.8	29.2	0.9	16.8
	27/10/99	0.7	5.2	0.6	3.0	0.8	1.2	109.1	3.0	27.6	0.8	19.6
	30/09/99	1.0	0.0	5.6	0.7	2.2	0.8	1.4	131.2	52.1	0.8	21.9
	16/09/99		5.8	1.0	2.9	0.6	0.8	96.0	3.0	52.0	0.8	28.2

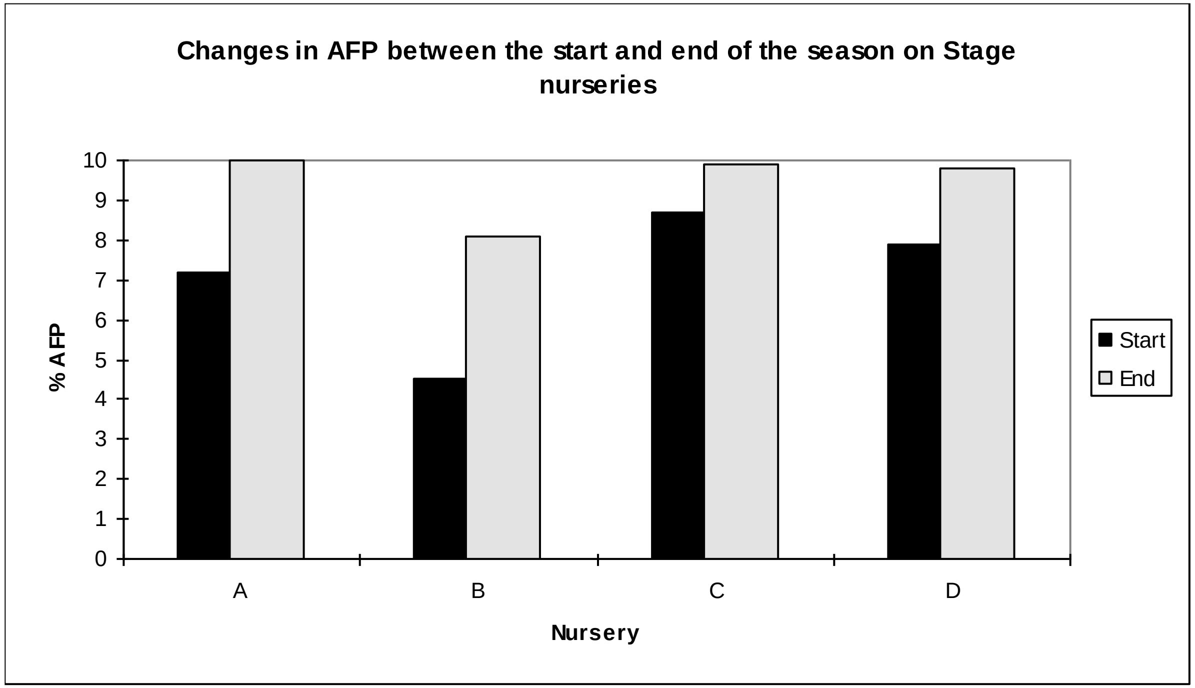

% Nitrogen in leaf tissue
% Nitrogen
0
1
2
3
4
5
6
7
36-37
38-39
40-41
42-43
44-45
46-47
48-49
Week number
% Nitrogen A
% Nitrogen B
% Nitrogen C

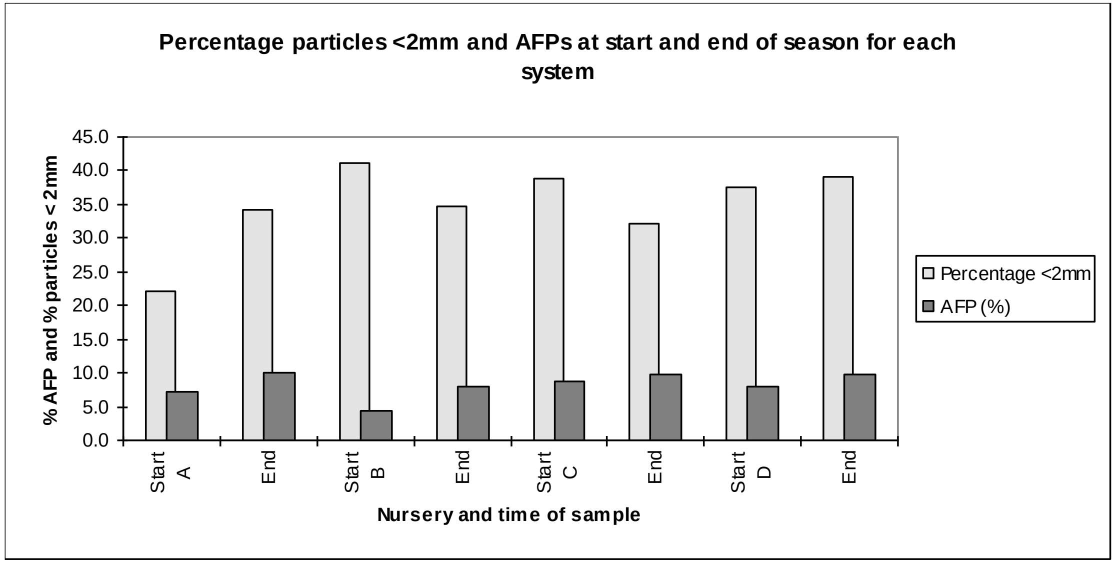
Appendix XVII - Chart to show Average pH of irrigation and run-off water in Stage 2 nurseries



Appendix XVIII - Mean sieve analysis and AFP results for Stage 2 nurseries

Nursery	Sample taken	13.2mm	9.5mm	6.7mm	4.8mm	3.4mm	2.0mm	1.0mm	0.5mm	0.1mm	Pan	AFP (%)
A	Start	26.8	21.4	10.0	9.9	9.5	8.7	5.4	4.8	3.3	0.3	7.2%
	End	20.9	14.5	9.5	9.2	11.6	12.3	10.9	7.3	3.7	0.2	10.0
B	Start	12.7	13.4	9.8	10.8	9.4	11.4	10.4	9.3	10.1	2.8	4.5%
	End	13.8	16.5	12.8	9.9	11.2	12.2	9.2	7.9	5.4	1.2	8.1
C	Start	8.1	13.9	13.1	14.0	10.6	9.7	9.7	9.1	10.4	1.3	8.7%
	End	13.7	21.7	15.8	8.6	6.7	7.0	7.2	8.4	9.5	1.4	9.9
D	Start	10.8	13.3	11.7	14.4	9.6	10.5	10.1	9.1	7.9	2.6	7.9%
	End	12.9	16.3	9.2	11.1	9.6	10.6	9.8	9.3	9.5	1.8	9.8


Changes in AFP between the start and end of the season on Stage nurseries
% AFP
10
9
8
7
6
5
4
3
2
1
0
A
B
C
D
Nursery
Start
End



Percentage particles <2mm and AFPs at start and end of season for each system
% AFP and % particles < 2mm
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Start
A
End
Start
B
End
Start
C
End
Start
D
End
Nursery and time of sample
Percentage <2mm
AFP (%)

Appendix XIX - Plant quality scoring for Stage 2 plants

Nursery	Variety	Rep	Plant	Date of record	Height (cm)	Spread (cm)	Primary Breaks	Secondary Breaks	Total Breaks (auto)	Average Star size Class (1 - 4)	Average Cyathia Size (1,2,3)	Stage of Cyathia Development (1 - 6)	Grassy Growth (0, 1, 3)	Sleevability (1, 3, 5)	Plant Quality (0,1,2)
A	sonora	1	1	29th Nov 99	31	47	3	4	7	25	1	1	0	5	1
	sonora	1	2		27	46	5	4	9	24	1	2	2	5	2
	sonora	1	3		22	38	5	3	8	17	1	2	1	5	1
	sonora	1	4		28	48	5	3	8	22	1	3	0	5	2
	sonora	1	5		25	43	7	1	8	21	1	1	0	5	2
	sonora	1	6		29	42	5	4	9	23	1	2	0	5	2
	sonora	1	7		26	40	6	1	7	24	1	1	0	5	2
	sonora	1	8		27	31	2	7	9	28	1	1	0	5	1
	sonora	1	9		26	39	3	5	8	25	1	2	0	5	2
	sonora	1	10		27	41	5	1	6	26	1	1	0	5	2
	sonora	2	1		29	40	6	0	6	27	1	2	2	5	2
	sonora	2	2		24	45	5	4	9	24	1	2	1	5	2
	sonora	2	3		24	39	4	3	7	24	1	2	0	5	2
	sonora	2	4		28	43	5	3	8	22	1	2	0	5	2
	sonora	2	5		24	42	5	1	6	22	1	2	0	5	2
	sonora	2	6		26	41	4	3	7	21	1	2	0	5	2
	sonora	2	7		26	42	5	2	7	21	1	1	0	5	2
	sonora	2	8		23	42	7	1	8	21	1	1	0	5	2
	sonora	2	9		28	42	4	5	9	20	1	1	0	5	1
	sonora	2	10		27	46	4	1	5	28	1	1	0	5	2

Nursery	Variety	Rep	Plant	Date of record	Height (cm)	Spread (cm)	Primary Breaks	Secondary Breaks	Total Breaks (auto)	Average Star size Class (1 - 4)	Average Cyathia Size (1,2,3)	Stage of Cyathia Development (1 - 6)	Grassy Growth (0, 1, 3)	Sleevability (1, 3, 5)	Plant Quality (0,1,2)
B	sonora	1	1	8th Dec 99	28	40	5	2	7	23	1	2	2	5	2
	sonora	1	2		30	41	3	3	6	25	2	2	1	5	1
	sonora	1	3		25	38	2	3	5	24	1	2	1	5	1
	sonora	1	4		27	42	5	3	8	26	2	4	2	5	2
	sonora	1	5		28	40	4	3	7	21	1	3	2	5	2
	sonora	1	6		30	40	4	2	6	27	2	3	2	5	2
	sonora	1	7		30	41	2	3	5	24	1	2	3	5	1
	sonora	1	8		30	44	4	3	7	23	2	2	2	5	2
	sonora	1	9		28	47	5	1	6	21	2	3	2	5	2
	sonora	1	10		29	44	6	1	7	27	2	4	3	3	2
	sonora	2	1		32	43	4	3	7	27	1	2	3	5	2
	sonora	2	2		22	39	5	1	6	18	1	2	3	5	2
	sonora	2	3		25	47	5	2	7	23	1	2	0	5	2
	sonora	2	4		24	48	5	1	6	19	1	2	3	5	2
	sonora	2	5		30	44	4	3	7	24	1	2	3	5	2
	sonora	2	6		26	39	5	0	5	24	1	2	3	5	2
	sonora	2	7		32	47	4	4	8	29	2	3	0	5	2
	sonora	2	8		29	43	5	1	6	21	1	2	3	5	2
	sonora	2	9		31	39	3	4	7	26	1	4	3	5	1
	sonora	2	10		32	41	5	2	7	25	2	4	2	5	2

Nursery	Variety	Rep	Plant	Date of record	Height (cm)	Spread (cm)	Primary Breaks	Secondary Breaks	Total Breaks (auto)	Average Star size Class (1 - 4)	Average Cyathia Size (1,2,3)	Stage of Cyathia Development (1 - 6)	Grassy Growth (0, 1, 3)	Sleevability (1, 3, 5)	Plant Quality (0,1,2)
C	sonora	1	1	20th Nov 99	30	40	4	3	7	25	1	2	0	5	2
	sonora	1	2		24	38	3	4	7	21	1	1	0	5	1
	sonora	1	3		26	40	3	2	5	21	1	2	0	5	1
	sonora	1	4		21	47	4	1	5	24	1	1	0	5	1
	sonora	1	5		24	39	6	0	6	22	1	1	0	5	2
	sonora	1	6		27	40	3	3	6	27	1	1	0	5	1
	sonora	1	7		27	45	4	1	5	27	1	2	0	5	2
	sonora	1	8		27	47	4	2	6	27	1	3	0	5	2
	sonora	1	9		24	42	5	0	5	27	1	1	0	5	2
	sonora	1	10		26	36	3	3	6	27	1	2	0	5	1
	sonora	2	1		28	45	5	1	6	25	1	1	0	5	2
	sonora	2	2		28	43	4	1	5	28	1	2	0	5	1
	sonora	2	3		25	41	5	2	7	26	1	1	0	5	2
	sonora	2	4		16	43	5	1	6	21	1	1	0	5	1
	sonora	2	5		23	43	5	1	6	23	1	2	0	5	2
	sonora	2	6		21	42	5	0	5	22	1	2	0	5	2
	sonora	2	7		27	38	5	1	6	23	1	1	0	5	2
	sonora	2	8		25	40	4	2	6	27	1	2	0	5	2
	sonora	2	9		25	42	5	1	6	26	1	1	0	5	2
	sonora	2	10		29	42	5	1	6	28	1	2	0	5	2

Nursery	Variety	Rep	Plant	Date of record	Height (cm)	Spread (cm)	Primary Breaks	Secondary Breaks	Total Breaks (auto)	Average Star size Class (1 - 4)	Average Cyathia Size (1,2,3)	Stage of Cyathia Development (1 - 6)	Grassy Growth (0, 1, 3)	Sleevability (1, 3, 5)	Plant Quality (0,1,2)
D	Malibu	1	1	10th Dec 99	25	39	5	1	6	24	1	2	0	5	2
	Malibu	1	2		22	42	6	1	7	23	1	2	0	5	2
	Malibu	1	3		27	43	3	5	8	23	1	1	0	5	2
	Malibu	1	4		23	40	4	2	6	25	1	2	0	5	1
	Malibu	1	5		23	37	5	2	7	18	1	1	0	5	1
	Malibu	1	6		22	36	4	2	6	21	1	2	0	5	1
	Malibu	1	7		24	41	5	0	5	19	1	1	0	5	1
	Malibu	1	8		27	50	6	2	8	23	2	2	0	4	2
	Malibu	1	9		22	45	5	1	6	25	1	2	0	5	2
	Malibu	1	10		28	47	5	0	5	26	1	1	0	5	2
	Malibu	2	1		28	44	4	3	7	27	2	3	0	5	2
	Malibu	2	2		23	38	6	1	7	13	1	1	0	5	0
	Malibu	2	3		21	36	3	2	5	22	2	3	0	5	1
	Malibu	2	4		23	39	7	1	8	22	1	2	0	5	2
	Malibu	2	5		24	44	3	4	7	25	2	2	0	5	1
	Malibu	2	6		19	41	5	3	8	19	1	1	0	5	1
	Malibu	2	7		24	38	5	2	7	19	2	3	0	5	1
	Malibu	2	8		24	41	5	3	8	19	1	2	0	4	2
	Malibu	2	9		20	37	4	2	6	27	1	2	0	5	1
	Malibu	2	10		26	40	4	3	7	28	1	2	0	5	2

ANOVA tables for heights of Poinsettias at each nursery in Stage 2

Nursery A

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	20	598	29.9	1.778947
Column 2	20	527	26.35	4.976316

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	126.025	1	126.025	37.31165	4.04E-07	4.098169
Within Groups	128.35	38	3.377632			
Total	254.375	39				

SIGNIFICANTLY SHORTER THAN SPECIFICATION

Nursery B

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	20	598	29.9	1.778947
Column 2	20	568	28.4	7.936842

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22.5	1	22.5	4.631636	0.037804	4.098169
Within Groups	184.6	38	4.857895			
Total	207.1	39				

JUST
SIGNIFICANTLY SHORTER THAN SPECIFICATION

Nursery C

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	20	598	29.9	1.778947
Column 2	20	503	25.15	10.34474

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	225.625	1	225.625	37.22053	4.14E-07	4.098169
Within Groups	230.35	38	6.061842			
Total	455.975	39				

SIGNIFICANTLY SHORTER THAN SPECIFICATION

Nursery D

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	20	598	29.9	1.778947
Column 2	20	475	23.75	6.302632

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	378.225	1	378.225	93.60176	8.49E-12	4.098169
Within Groups	153.55	38	4.040789			
Total	531.775	39				

SIGNIFICANTLY SHORTER THAN SPECIFICATION

Appendix XX - Breakdown of system costings

Ebb & Flow Floor (Recirculated)

Description

The glasshouse is divided into 8 separate flood floors. Each being 25m x 19.2m. Water from a large storage tank, sufficient to hold one days flood water, is pumped into each floor, one at a time, to a depth of 3cm. Water is then drained to a sump, where it is pumped back into a storage tank via a disc and UV filter. Mains water is added to the storage tank as required. 75% of the water is reused.

Equipment

	Item	Quantity	Cost (£)	Total (£)	
	Leveling & constructing concrete floor (per sq.m)	3840	27.80	106752.00	
	Tank set (24 cu.m)	1	1200.00	1200.00	
	Mains water refill set	1	135.00	135.00	
	Flood set (one per two bays)	4	270.00	1080.00	
	Sump set	1	245.00	245.00	
	Control set	1	485.00	485.00	
	Solenoid valve set (one per two bays)	4	75.00	300.00	
	Linking pipework set	8	95.00	760.00	
	Disc and UV ozone filter set	1	1400.00	1400.00	
			Total	**112357.00**	
Labour	Man days to install equipment	9	225.00	2025.00	
			Total	**2025.00**	
Maintenance over 10 years					
	Repairs and renewals	10	30.00	300.00	
			Total	**300.00**	
Annual Running Costs					
	Labour (man days)	23	52.00	1196.00	
	Water @ 34.6 litres per sq.m per week	1328640	0.61	810.47	
			Total	**2006.47**	
	Total costs for setting up	114382.00		28.60	per sq.m
	Total costs for running	2036.47		2036.47	per annum

Ebb & Flow Floor (To waste)

Description
The glasshouse is divided into 8 separate flood floors. Each being 25m x 19.2m. Water from a storage tank, sufficient to hold one days flood water, is pumped into each floor, one at a time, to a depth of 3cm. Water is then drained and run to waste.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	Leveling & constructing concrete floor (per sq.m)	3840	27.80	106752.00
	Tank set (24 cu.m)	1	1200.00	1200.00
	Mains water refill set	1	135.00	135.00
	Control set	1	485.00	485.00
	Solenoid valve set (one per two bays)	4	75.00	300.00
	Linking pipework set	8	95.00	760.00
			Total	**109632.00**
Labour	Man days to install equipment	7	225.00	1575.00
			Total	**1575.00**
Maintenance over 10 years				
	Repairs and renewals	10	50.00	500.00
			Total	**500.00**
Annual Running Costs				
	Labour (man days)	23	52.00	1196.00
	Water @ 34.6 litres per sq.m per week	5314560	0.61	3241.88
			Total	**4437.88**

Total costs for setting up	111207.00	27.80 per m2
Total costs for running	4487.88	4487.88 per annum

Ebb & Flow Benches (Recirculated)

Description
The glasshouse is fitted with mobile/static benches containing ebb and flow inserts. Each bench is 1.846m x 24m. They are supplied by water from a storage tank, sufficient to hold at least one days flood water. Water is pumped into each bench to a depth of 3cm. Water is then drained to a sump, where it is pumped back into a storage tank via a disc and UV filter. Mains water is added to the storage tank as required. 7/8th of the water is reused.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	Benching (1.846m x 24m)	72	886.00	63792.00
	Ebb & flow inserts per sq.m	3110	14.50	45095.00
	Tank set	1	1200.00	1200.00
	Mains water refill set	1	135.00	135.00
	Flood set (one per two bays)	4	270.00	1080.00
	Sump set	1	245.00	245.00
	Control set	1	485.00	485.00
	Solenoid valve set(one per two bays)	4	75.00	300.00
	Linking pipework set	8	95.00	760.00
	Disc and UV ozone filter set	1	1400.00	1400.00
			Total	**114492.00**
Labour	Man days to install	83	225.00	18675.00
			Total	**18675.00**
Maintenance over 10 years				
	Repairs and renewals	10	50.00	500.00
			Total	**500.00**
Annual Running Costs				
	Labour (man days)	23	52.00	1196.00
	Water @ 34.6 litres per sq.m per week	1103394	0.61	673.07
			Total	**1869.07**
	Total costs for setting up	133167.00		33.29 per m2
	Total costs for running	1919.07		1919.07 per annum

Ebb & Flow Benches (To waste)

Description

The glasshouse is fitted with mobile/static benches containing ebb and flow inserts. Each bench is 1.846 x 24m. The benches are supplied by water from a storage tank, sufficient to hold one days flood water. Water is pumped into each bench to a depth of 3cm. Water is then drained and run to waste.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	Benching (1.846m x 24m)	72	886.00	63792.00
	Ebb & flow inserts	3110	14.50	45095.00
	Tank set	1	1200.00	1200.00
	Mains water refill set	1	135.00	135.00
	Control set	1	485.00	485.00
	Solenoid valve set(one per two bays)	4	75.00	300.00
	Linking pipework set	8	95.00	760.00
			Total	**111767.00**
Labour	Man days to install	79	225.00	17775.00
			Total	**17775.00**
Maintenance over 10 years				
	Repairs and renewals	10	80.00	800.00
			Total	**800.00**
Annual Running Costs				
	Labour (man days)	23	52.00	1196.00
	Water @ 34.6 litres per sq.m per week	4413576	0.61	2692.28
			Total	**3888.28**
	Total costs for setting up	129542.00		32.39 per m2
	Total costs for running	3968.28		3968.28 per annum

Gantry

Description

Water is supplied from the mains via a storage tank. It is then piped into the glasshouse and to the ends of each bay via a 75mm pipe. Gantries running the width of the bay are then fed from these pipes through a 32mm pipe. Each gantry has its own motor, controlled from a central control system, with on, off, auto and test function. Watering can be applied on the up or down path or both. 80-degree fan nozzles are used.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	PVC Pressure Pipe 10 bar 5m x 75mm	42	12.30	516.60
	1 litre Saba S3 Glue	4	15.10	60.40
	1 litre Saba cleaning fluid	1	8.90	8.90
	Double union valve	3	56.55	169.65
	75mm x 32mm x 75mm Tee Piece	24	4.98	119.52
	End cap	2	3.53	7.06
	PVC Pressure Pipe 10 bar 5m x 32mm	10	3.45	34.50
	PVC Pressure Pipe 90 degree bend 32mm	24	1.30	31.20
	PVC Pressure Pipe 90 degree bend 75mm	2	5.28	10.56
	Solenoid	24	40.00	960.00
	Gantries	24	3400.00	81600.00
	Track (25 m per bay)	600	3.00	1800.00
	Control System	1	2000.00	2000.00
			Total	**87318.39**
Labour	Man days to install	24	225.00	5400.00
			Total	**5400.00**
Maintenance over 10 years				
	Repairs and renewals	10	50.00	500.00
	Replacement nozzles	100	0.80	80.00
	Replacement hoses	24	40.00	960.00
			Total	**1540.00**
Annual Running Costs				
	Labour only	23	52.00	1196.00
	Water @ 14 litres per sq.m per week	2150400	0.61	1311.74
			Total	**2507.74**
	Total costs for setting up	92718.39		23.18 per m2
	Total costs for running	2661.74		2661.74 per annum

Overhead

Description

Water is supplied into the glasshouse from a storage tank. It is run to each bay via two 75mm pipes. From these pipe each bay has 2 runs of 32mm pipe running its length. Into these 32mm pipes Dutch pin nozzles are used at 0.8-m centres.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	PVC Pressure Pipe 10 bar 5m x 75mm	42	12.30	516.60
	1 litre Saba S3 Glue	6	15.10	90.60
	1 litre Saba cleaning fluid	1	8.90	8.90
	Double union valve	3	56.55	169.65
	75mm x 32mm x 75mm Tee Piece	24	4.98	119.52
	End cap	2	3.53	7.06
	PVC Pressure Pipe 10 bar 5m x 32mm	250	3.45	862.50
	PVC Pressure Pipe 90 degree bend 32mm	24	1.30	31.20
	PVC Pressure Pipe 90 degree bend 75mm	2	5.28	10.56
	Dutch Pin Nozzles per 0.8m	1500	0.24	360.00
	Solenoid	48	40.00	1920.00
	Control set and electrics	1	500.00	500.00
			Total	**4596.59**
Labour	Man days to install	10	225.00	2250.00
			Total	**2250.00**
Maintenance over 10 years				
	Repairs and renewals	10	20.00	200.00
	Replacement nozzles	100	0.24	24.00
			Total	**224.00**
Annual Running Costs				
	Labour only	23	52.00	1196.00
	Water @ 30 litres per sq.m per week	4608000	0.61	2810.88
			Total	**4006.88**
	Total costs for setting up	6846.59		1.71 per m2
	Total costs for running	4029.28		4029.28 per annum

Hand-watering

Description

The glasshouse has two 75mm mains feed via cut off valves, running the length of glasshouse, situated at the central path end. A 32mm feed pipe then leads to a Geeka valve, with a single take-off per bay. A 19mm hose on reel with trigger lance is then attached and used.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	PVC Pressure Pipe 10 bar 5m x 75mm	32	12.30	393.60
	1 litre Saba S3 Glue	2	15.10	30.20
	1 litre Saba cleaning fluid	1	8.90	8.90
	Double union valve	1	56.55	56.55
	75mm x 32mm x 75mm Tee Piece	24	4.98	119.52
	End cap	2	3.53	7.06
	PVC Pressure Pipe 10 bar 5m x 32mm	10	3.45	34.50
	PVC Pressure Pipe 90 degree bends	4	5.28	21.12
	Nickel plated ball valve 32mm	24	4.42	106.08
	Male coupling 32mm	24	1.14	27.36
	Coupling 19mm	4	1.51	6.04
	Jubilee clip	4	0.30	1.20
	Hose 50m x 19mm	2	41.00	82.00
	Hose guide	2	74.25	148.50
	Trigger lance	2	54.90	109.80
	Aluminium rose	2	5.10	10.20
			Total	**1162.63**
Labour	Man days to install	3	225.00	675.00
			Total	675.00
Maintenance over 10 years				
	Repairs and renewals	10	20.00	200.00
	Replacement lances	2	54.90	109.80
	Replacement roses	10	5.10	51.00
			Total	**360.80**
Annual Running Costs				
	Labour (man days)	90	52.00	4680.00
	Water @ 8.4 litres per sq.m per week	1290240	0.61	787.05
			Total	**5467.05**
	Total costs for setting up	1837.63		0.46 per m2
	Total costs for running	5503.13		5503.13 per annum

Capillary Matting

Description

The glasshouse has two 75mm mains feed via cut off valves, running the length of glasshouse. A 32mm feed pipe then leads to a Geeka valve, with a single take-off per bay. From these Trickle Irrigation is attached. 4 lengths of 1.4 matting are used per bay. Irrigated by the trickle tape, at 0.6cm spacing. Covered with micro-porous polythene. The matting is laid on a polythene sheet.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	PVC Pressure Pipe 10 bar 5m x 75mm	42	12.30	516.60
	PVC Pressure Pipe 90 degree bend 75mm	2	5.28	10.56
	1 litre Saba S3 Glue	3	15.10	45.30
	1 litre Saba cleaning fluid	1	8.90	8.90
	Double union valve	3	56.55	169.65
	75mm x 32mm x 75mm Tee Piece	24	4.98	119.52
	End cap	2	3.53	7.06
	PVC Pressure Pipe 10 bar 5m x 32mm	20	3.45	69.00
	Nickel plated ball valve 32mm	24	1.30	31.20
	Male coupling 32mm	24	0.78	18.72
	Polythene 80/20 3.6 x 100m	11	30.25	332.75
	Capillary matting 1.40m x 50m	48	74.65	3583.20
	Micro-perforated polythene	6	94.50	567.00
	Trickle tape 2 runs per mat	5	159.00	795.00
	Centre feed pack	24	5.45	130.80
	Header Pipe (25mm x 100m)	2	49.00	98.00
	Entry fittings (packs of 10)	24	4.80	115.20
	Hose 25m x 25mm	1	35.00	35.00
	Hose Geeka coupling	24	1.54	36.96
	Jubilee clips	24	0.27	6.48
	Punch Kit	1	12.00	12.00
			Total	**6708.90**
Labour	Man days to install	10	225.00	2250.00
			Total	**2250.00**
Maintenance over 10 years				
	Replacement Trickle every 4 years	2.5	1139.00	2847.50
	Replacement matting every 4 years	2.5	3583.20	8958.00
	Replacement micropolythene every year	10	567.00	5670.00
	Replacement jubilee clips	2	0.27	0.54
	Replacement couplings	10	1.54	15.40
			Total	**17491.44**

Annual Running Costs

Labour only	23	52.00	1196.00
Water @12 litres per sq.m per week	1843200	0.61	1124.35
		Total	**2320.35**

Total costs for setting up	8958.90	2.24 per m2
Total costs for running	4069.50	4069.50 per annum

Drip

Description
Two 75mm header mains runs the length of the glasshouse. One each end. 32mm feed to each bay leading to 10 lines of 20 x 17mm LDPE pipe. Off each pipe are 3.2 x 0.9mm capillary pipes at 30cm intervals. Pipes come pre-fitted with drip lines

Equipment

	Item	Quantity	Cost (£)	Total (£)
	PVC Pressure Pipe 10 bar 5m x 75mm	42	12.30	516.60
	PVC Pressure Pipe 90 degree bend 75mm	2	5.28	10.56
	1 litre Saba S3 Glue	3	15.10	45.30
	1 litre Saba cleaning fluid	1	8.90	8.90
	Double union valve	3	56.55	169.65
	75mm x 32mm x 75mm Tee Piece	24	4.98	119.52
	End cap	2	3.53	7.06
	PVC Pressure Pipe 10 bar 5m x 32mm	20	3.45	69.00
	Nickel plated ball valve 32mm	24	1.30	31.20
	Male coupling 32mm	24	0.78	18.72
	CNL units	0	4.42	0.00
	20 x 17mm LDPE pipe (250m per bay)	60	24.00	1440.00
	3.2 x 0.9mm capillary tube (85cm each)	19200	0.11	2112.00
	Aquastakes	19200	0.09	1728.00
			Total	**6276.51**
Labour	Man days to install	24	225.00	5400.00
			Total	**5400.00**
Maintenance over 10 years				
	Repairs and renewals	10	20.00	200.00
	Replacement tubes	100	0.06	6.00
	Replacement stakes	100	0.06	6.00
			Total	**212.00**
Annual Running Costs				
	Labour only	23	52.00	1196.00
	Water @ 3.7 litres per sq.m per week	568320	0.61	346.68
			Total	**1542.68**
	Total costs for setting up	11676.51		2.92 per m2
	Total costs for running	1563.88		1563.88 per annum

Trough Track

Description

The glasshouse is fitted with rails (4.5m) and carriers on to which troughs (15cm x 6.2m) are fitted. 12 tracks are fitted as standard but more or less can be fitted depending on crop requirements. Troughs are supplied by water from a storage tank, sufficient to hold at least one days flood water. Water is pumped into each bench to a depth of 3cm. Water is then left until used, evaporated or run-off.

Equipment

	Item	Quantity	Cost (£)	Total (£)
	Rails, Carriers and troughs	4000	20.56	82240.00
	Tank set	1	1200.00	1200.00
	Mains water refill set	1	135.00	135.00
	Flood set (one per two bays)	4	270.00	1080.00
	Sump set	1	245.00	245.00
	Control set	1	485.00	485.00
	Solenoid valve set(one per two bays)	4	75.00	300.00
	Linking pipework set	8	95.00	760.00
	Disc and UV filter set	1	1400.00	1400.00
			Total	**87845.00**
Labour	Man days to install	83	225.00	
			Total	**18675.00**
Maintenance over 10 years				
	Repairs and renewals	10	50.00	
			Total	**500.00**
Annual Running Costs				
	Labour (man days)	23	52.00	1196.00
	Water @ litres per sq.m per week		0.61	2061.31
			Total	**3257.31**

Total costs for setting up 26.63 per m2

Total costs for running 3307.31 per annum

