CONTRACT REPORT

Glasshouse irrigation: A review of R & D and evaluation of current techniques for edible crops grown in hydroponic systems

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Project leader:	**Mike Fussell, HRI Efford Lymington Hants SO41 OLZ**
Co-authors of report:	**Gerry Hayman, Horticultural Consultant, Littleplace, West Walberton Lane, Walberton, Arundel, W. Sussex BN18 OQS. Alan Wright, Tomato Crop Consultant, 109 Castle Road, Rowlands Castle, Hampshire PO9 6BL.**
Project Co-ordinator:	**Nigel Dungey**
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CONTENTS

1. Practical Section for Growers

Background and Objectives

A review of the current state of knowledge about the irrigation of edible crops grown in hydroponics was undertaken. A literature review of research and a survey of the irrigation practices of 25 tomato, 6 cucumber and 3 pepper growers were completed. This information together with the experiences of two independent crop consultants was used to formulate a list of key areas where growers could improve irrigation practice based on current knowledge and to identify further research and development that is required in order that further improvements can be made.

Improved irrigation is likely to result in improved crop growth, yield and fruit quality while also reducing waste of water and nutrients. The review does not address the issue of recirculation in substrate grown crops which would result in the greatest reductions in waste.

Action Points for Growers

Many growers could improve irrigation practice by:

* Calculating irrigation volume on an area basis (per m^2 not per plant)

* Using calibrated litre counters to measure applied volume (not time)

* Checking variations in dripper output regularly in order to identify problems at an early stage

* Ensuring the capacity of irrigation systems is high enough to supply plant requirements for water during the brightest hours of sunny days

* Calibrating solarimeters regularly and taking account of glasshouse light transmission

* Investment in more accurate dripper systems

* Careful attention to the positioning of drainage slits

Areas for Further Research

The review highlighted a number of areas where further research and development are required:

* **Improving the match between water supply and water demand**, particularly in dull weather when irrigation is largely controlled by time. This could be achieved through the development of irrigation control based on predictions of transpiration from environmental variables or from transpiration sensors. In the short term the use of slab moisture, slab weighing devices, start trays and drainage volume and EC to trigger starts instead of time are likely to result in improved performance.

* **Water use by crops in NFT and rockwool** run-to-waste systems are substantially different according to current information. If as grower data suggests, water use in NFT is less, research is needed to establish why.

* **The roles of slab moisture content, aeration, EC and fluctuations in these variables in determining crop growth, yield and fruit quality need to be established.**

* **Overcoming plant resistance to water uptake.** There is a need for fundamental research into mechanisms influencing water uptake in order that problems of water uptake lagging behind transpiration, particularly when weather conditions change from dull to bright can be overcome.

* **Improving the accuracy of delivery systems.** Survey results indicated large variations in dripper outputs. The drain-back and refilling that occurs in most systems is likely to account for much of this variation. CNL drippers may improve the accuracy of drippers and a more uniform distribution of water is likely to result if irrigation supply lines are arranged as in the Tichelmann system, a circulatory system designed so that the route taken by water through the irrigation lines is equal for all supply lines.

2. Introduction

'The availability of soil water is one of the environmental factors that frequently limits growth and yield' (Salter 1957). Is it possible that this statement might still hold true for modern day glasshouse crops of tomato, pepper and cucumber grown in substrates with computerised irrigation control? The issues of interest today including fruit quality, costs of water and feed and avoidance of environmental pollution as well as yield are different from those of 1957 but the simple requirement for water by the plant remains the same. The purpose of irrigation is simple - to replenish water and nutrients used by the plant. Finding an effective means of doing this without overwatering is more difficult. This review does not address recirculation. The recirculation of solutions in substrate grown crops is a major issue and would result in significant savings on costs of water and nutrients by reducing waste.

Past and current R & D has led to a number of relevant findings which are reviewed in section 4. A review of current commercial practice is outlined in Section 5 drawing upon the results of a grower questionnaire and upon the experience of crop consultants. The deficiencies in current practice from Section 5 coupled with recent advances in R & D from Section 4 are used as a basis for comments on how growers can improve their systems based on current knowledge in Section 6 and to propose a list of priorities for future R & D in Section 7.

3. Review of Research

3.1 Evapotranspiration and irrigation control

The water requirement of plants, including tomato, pepper and cucumber is largely driven by transpiration with only small amounts of water being used for plant growth. The early work of Penman (1948) showed that transpiration of grass could be closely related to solar radiation and wind velocity. In the glasshouse where wind velocity is of lesser importance, the transpiration of crops at full leaf cover is closely related to solar radiation (Morris et al 1957). Hand *et al* (1970) found considerable variation in water use within a tomato crop depending upon position in the house. On bright sunny days up to 23% more water was evaporated from southernmost plants than the crop average and up to 11% less in northern beds. Work at Fairfield and Efford (Forsdyke 1974) showed that irrigation based on solar radiation was justified provided allowances were made for differences in light transmission between glasshouses and differences in light utilisation for transpiration due to crop stage.

Current practice still largely relies on solar radiation as the only environmental criterion used to control irrigation. Secondary control on time is also used in order that substrates do not dry out in periods of dull weather when there are few or no applications based on solar radiation. There are undoubtedly occasions when this combination results in inappropriate quantities of water being applied to crops. De Graaf (1996) argues that dry summer winds can result in 35% higher evapotranspiration than would be predicted on the basis of solar radiation alone. There is also debate regarding the role of radiation from heating pipes on the evaporative demand of crops. Lake et al (1963) found pipe heat to have only a very small influence on plant water requirements. However in winter and with the dumping into the glasshouse of heat used to produce CO_2 there may be a greater effect. De Graaf (1996) estimates that in winter 60% of evaporation is due to radiation from the heating pipes. There is therefore a need to make predictions of transpiration based on other factors as well as solar radiation.

In recent years attempts have been made to model transpiration. Stanghellini and van Meurs(1992) described a climate control algorithm designed to achieve a desired transpiration rate by manipulation of glasshouse air temperature and vapour pressure deficit. Work in Japan (Kitano & Eguchi 1991) has shown that evaporative demand can be manipulated by changes to the humidity of the environment. Work at Silsoe Research Institute as part of the EU funded Management and Control for Quality in Greenhouses (MACQU) project found that in a simulation model relating transpiration to leaf area index, solar radiation and saturation deficit (inside), solar radiation accounted for most of the variation in transpiration and in combination with saturation deficit accounted for 98.5% of variation while there was a full crop canopy. However when the predicted water use was compared to that in NFT and rockwool grown crops of tomatoes the simulation model was found to underestimate the water requirement particularly when saturation deficits were large and at night. A refined irrigation model based on the Penman-Monteith equation gave better results and will be further validated. (P Hamer pers. comm.)

The Penman-Monteith equation is an energy balance equation that allows the energy used in transpiration to be calculated from environmental variables within the plant canopy and requires a knowledge of stomatal and boundary layer resistances to the transfer of water vapour (Monteith & Unsworth 1990). The Penman-Monteith equation has been adapted by a number of workers to provide estimates of evapotranspiration for crops. Norrie et al (1994) found potential evapotranspiration to be closely correlated with substrate matrix potential (moisture) measured using electronic tensiometers in peat bags. Boulard & Jemaa (1993) found a good agreement between predicted transpiration and water use by a tomato crop as measured by lysimeters and by water budget calculations. However their model included complex crop parameters such as leaf area index and the aerodynamic resistance to water vapour transfer which could not be easily incorporated into an irrigation control program. They discuss simpler models using solar radiation and vapour pressure deficit as its main components. There is still only one irrigation control software available through the main suppliers, Hoogendoorn's "agronaut", that operates on the basis of predicted transpiration.

A further factor not normally considered in the estimation of evapotranspiration is carbon-dioxide concentration. De Graaf (1990) found that in peppers (c.v Mazurka) increasing the CO_2 concentration from 300 vpm to 800 or 1200 vpm resulted in a reduction in evapotranspiration of 15-20%. The reduction in transpiration was associated with enhanced stomatal resistance, especially in the uppermost leaves. However Nederhoff et al (1992) found that while CO_2 did reduce stomatal conductance in pepper, complex feedback mechanisms meant that the apparent effect on evapotranspiration was relatively small. In tomato (c.v. Calypso) and cucumber (c.v. Jessica) CO_2 enrichment was also found to have a negligible effect on evapotranspiration despite an apparent effect on stomatal conductance (Nederhoff & De Graaf 1993).

A different approach is to measure potential transpiration rather than to try to predict it from environmental factors. In the past Jones-Rothwell evaporimeters were widely used to determine irrigation in soil grown crops. Thom et al (1981) and Papaioannou *et al* (1996) found that piche atmometers were useful in estimating Penman's potential evapotranspiration. Artificial leaves have been constructed from filter paper representing cell walls in a real leaf and plastic tape (Loach 1983) or polystyrene (Harrison-Murray 1991) representing the impermeable upper leaf surface. Such evaporimeters have been designed for use in propagation environments. However such methods cannot account for plant factors such as stomatal conductance and leaf area indices that may influence actual transpiration. There is a need for sensors which measure transpiration within plants and for such sensors to be evaluated.

3.2 Optimising the root zone environment through irrigation

3.2.1 Irrigation frequency

An HDC funded trial (PC23c) in 1992 found no significant effects of applying smaller volumes more frequently as opposed to larger volumes less frequently on yield and fruit quality in tomato (Hand & Fussell 1993). Volumes per application were 50, 100, 200 or 400mls with the same total volumes applied dawn to dusk. Dutch research has shown a similar lack of response of yield and fruit quality to differences in the frequency/volume of irrigation starts when the overall daily volume is kept constant across treatments e.g. van Uffelen (1989), van Gurp & de Bruijn (1990), van der Burg (1990). A similar lack of response to different volumes/frequencies was found for cucumber in HDC PC61 (Hardgrave & Harriman 1995).

More recently work by Grodan in Holland has investigated the role of slab moisture content on yield. The experimental system employed a siphoning system to control slab moisture content with irrigation being constant across treatments. Slab moisture is likely to be affected by irrigation frequency. Small but frequent applications are likely to result in a higher moisture content than larger less frequent ones. Early trials found no difference in yield between slabs where moisture contents were maintained at 40% and 80% (Knop & Ouwerling, 1995). It seemed that tomato plants could adapt to a wide range of slab moisture contents. Subsequent trials (Blok 1996) have revealed some evidence that by maintaining low moisture contents (40%) higher yields to the end of May can result. De Koning and Hurd (1983) found that low slab moisture content promoted root growth and early production. Oxygen stress has been shown to lead to lower yields in Chrysanthemum. (Baas & Warmenhoven 1995). Tachibana (1988) found that in NFT withholding oxygen (no aeration of nutrient solution) by night resulted in very high levels of Blossom-End Rot, much higher than when oxygen was withheld during the day or where aeration continued all day and night.
Cobb et al (1995) found that root tips of maize seedlings formed under hypoxic conditions (supplied with 4% O_2) were able to survive anoxia (0% O_2) whereas roots formed under aerobic conditions (40% O_2) died when subjected to anoxia. This suggests that changes in slab conditions from dry to wet are likely to result in root problems as roots which developed at the base of the slab under a dry regime become waterlogged.

3.2.2 Substrate volume

Substrate volumes have decreased in recent years as a result of the use of smaller slabs and also because of the use of the 'V'-system of training plants in tomatoes. Work funded by HDC in the U.K. PC 23c (Hand & Fussell 1993), PC82 (Fussell & Hand 1994) showed that plants grown in the 'V'-system with 6.6 litres of substrate per m² compared well with those grown in conventional double rows with 13 litres per m². Hardgrave (1993) also found that the V-system could produce comparable yields to conventional double rows. In Holland van Gurp & Bruijn (1990) found no difference in tomato yield with root zone volumes of 7 -10.7 litres per m^2 but did find lower yield at 3.5 litres per m^2. Van Gurp (1991) found that smaller root zone volumes were also possible in both pepper and cucumber without yield loss and he recommended volumes of 10.5 and 7.0 litres per m^2 respectively.

3.2.3 Optimising the timing of irrigation

Extra waterings at different times of day or night in addition to waterings applied on the basis of a standard light triggered regime did not show any significant benefits in terms of yield or fruit quality (HDC PC82 - Fussell & Hand 1994). However these treatments were applied throughout a growing season irrespective of seasonal or daily changes in external weather conditions.

It has been shown that tomato plants can absorb large quantities of water at night e.g. Bailey (1994), Maruo et al (1995), but that they do not do this every night. Anon (1993) found that plant fresh weights fluctuate widely during the day. Following a bright day, water will continue to be absorbed into the night and during this time plant weights increase. Tomato and cucumber plants were found to differ in the extent that water was absorbed at night. In cucumber, the total water taken up by plants between sunrise and sunset was always greater than that lost by transpiration even on very bright days (>2600 J/cm^2). However in tomatoes on days with greater than 1600 J/cm^2 less water was absorbed than was lost to transpiration between sunrise and sunset leaving the plants in deficit. Subsequently, during the night, the weight increase for tomato was greater than that for cucumber as the plants recovered. The impact of such transient water stress on yield and fruit quality is not known. De Graaf (1996) makes the point that night waterings applied every night do not show any benefits and may do harm because of reduced root aeration but that in certain circumstances such as following bright days they may be beneficial.

There is evidence for differences in rates of evapotranspiration during different parts of the day. Gustafsson & Weich (1991) found that evapotranspiration was higher in the mornings than in the afternoon and they suggest that stomatal closure due to high temperatures may account for this. In contrast, work at Silsoe (Bailey 1994) suggests that in summer, estimates of transpiration based on solar radiation alone over-estimate transpiration in the morning but under estimate it in the afternoon compared to an estimate based on radiation and vpd.

As average daytime vpd changes from week to week so too does the accuracy of solar radiation in predicting transpiration and hence water requirements. Van de Ven (1993) considers that higher humidities from August onwards result in lower rates of evaporation than would be predicted from solar radiation alone and therefore he suggests reducing irrigation via less frequent irrigation starts and starting irrigation later and finishing earlier from August onwards to assist root aeration.

Overwatering in dull weather has been linked to fruit quality problems. Peet & Willits (1995) found that additional supply of feed solution caused a 20% increase in fruit cracking in tomatoes. Particular problems with splitting occur in truss tomatoes. At the South Netherlands Experimental Research Station the effects of delaying the start time of drip irrigation in the morning following a change from sunny to dull conditions was investigated (Anon 1997). However fruit splitting was not a problem in the trial so no firm conclusions could be drawn.

3.2.4 Root zone conductivity

Osmotic stress due to increased root zone electrical conductivity (EC) has been shown to reduce yield and fruit size while increasing fruit dry matter content (e.g. Nichols et al 1995). Tomato growers generally adjust applied EC seasonally, applying a higher EC (4-5mS/cm) in the winter to improve fruit quality and applying a lower EC (typically 2.5 - 3.0 mS/cm) in summer to maximise yield. Research is needed to determine whether varying applied EC continuously in response to light levels would result in a more stable root zone environment and prevent widely fluctuating plant water relations that may cause quality problems. Aikman & Houter (1990) suggested increasing EC during low light conditions to improve crop nutrition. Norrie *et al* (1994) suggest adjusting solution EC on the basis of potential evaporation.

Leaf scorch in tomatoes is associated with sudden changes in conditions from dull to bright and may be a result of partial wilting as the plant's ability to absorb water lags behind transpiration. Gauthier & Gosselin (1995) found that applying a feed solution at 4.5 mS/cm reduced the stomatal and cuticular transpiration rates and increased leaf waxiness in tomato plants compared to 2.5 mS/cm. Further research is required to determine if by maintaining a higher EC during dull conditions leaves become waxier and less prone to rapid water loss through transpiration so that partial wilting and leaf scorch may be avoided when conditions change to being bright.

3.3 Improving irrigation control to match plant requirements

It is clear that current irrigation practice using solar radiation as the main criterion to trigger waterings with time as a secondary controlling factor is unlikely to match water application accurately to plant needs. It is not known how crop yield and fruit quality would respond to improved control. In the absence of control programs based on predicted transpiration there is a need to find other ways of improving the delivery of water to match the plants' requirements, especially during dull periods or at night when timed waterings are used. MAFF funded work at HRI Stockbridge House (AU1390SPC, To study the effects of root environment on productivity and quality of greenhouse crops) has shown that the pattern of plant triggered irrigation supply (start trays) does not match that provided by the conventional light and time method. In particular, the standard system provided more irrigation in the afternoons than the plant triggered system. The project has also demonstrated the plants demand for water during the night. Although it is possible to meet the plants requirements using plant triggered systems it has yet to be proven whether irrigation on demand is the best way to optimise productivity and fruit quality. Preliminary results from this study do not show a significant benefit.

Another possibility is to trigger starts on the basis of substrate water content. Norrie *et al* (1994) used electronic tensiometers to measure substrate matric potential in peat bags and moisture meters are available for use on rockwool slabs. However there have been problems with such sensors and Silsoe Research Institute are developing new sensors that should be more reliable. Priva have developed a slab weighing device for determining slab water content that can be used to trigger irrigation starts (Cooke 1997).

4. Current Commercial Practice

In order to assemble information on current commercial practice, a survey was conducted in 1996 using a questionnaire (Appendix 1). Growers of cucumbers, peppers and tomatoes known to be producing crops in hydroponic systems were selected to give a range of production scale and location.

Completed questionnaires were returned in 34 cases; 6 for cucumbers, 3 for peppers and 25 for tomatoes.

In addition, information was collected from 5 tomato growers using recirculating NFT systems to obtain comparative data on crop water use.

Comments and conclusions are based on survey results and the experience of crop consultants.

4.1 Substrates

4.1.1 Type of material

Since inert substrates were introduced, a wide range of materials with differing characteristics in terms of water holding capacity and air content have become available. However in 1996 the majority of growers used rockwool (Table 1). Experience suggests that there are no consistent differences in yield or fruit quality due to type of substrate and that differences are likely to be grower dependent with choice of substrate depending upon individual growers' irrigation systems and strategies. There is no justification for further developmental work comparing manufactured substrates unless there is clearly an economic advantage to be gained in the form of lower material cost.

Table 1. Substrate material used by 30 growers in 1996

Substrate	Number of growers
Grodan rockwool	22
Cultilene rockwool	2
Cultilene glasswool	4
Tilcon perlite	1
Foam	1

There has been a trend towards the use of substrates with lower water holding capacities in recent years with Polyurethane foam being the most obvious example. If materials can be designed which encourage generative growth when accurately watered they could be of benefit to producers. This would have to be achieved without the negative effect on yield that is usually encountered when crops dry out accidentally. Vigorous crops, especially in the early part of the season are likely to benefit most from such developments.

4.1.2 Substrate volume per m² of crop

There is a continuing trend towards the adoption of the 'V' - system, in tomatoes, where two rows of plants derive from one row of roots. Sixty two percent of survey respondents used the 'V' - system in 1996. The figure for 1997 is likely to be higher still. In addition many tomato growers are now using plants propagated in 2 plant cubes. In the survey, volumes of substrate per m^2 of crop varied from 4 to 20 litres/m^2 for rockwool growers, 4 - 9 l/m^2 for glasswool. Differences in substrate volumes for different crops are listed in Table 2.

Table 2. Numbers of growers using different substrate volumes

	Substrate volume (l/m²)				
Crop	**4 - 6**	**6 - 8**	**8 - 10**	**10 - 12**	**12+**
Sweet Pepper	1				
Cucumber		1	2		
Tomato	7	9	3	3	4

Growers frequently discover mature plants still growing in the original 10x10x7.5cm blocks with no obvious growth restriction. There is no evidence from commercial experience to demonstrate increased yield or quality from higher substrate volumes. The key limiting factor is usually the irrigation supply system. Growers using higher volumes of substrate tended to do so because of fears concerning potential failure or inaccuracy of irrigation supply. The extra volume used by some growers is in effect an insurance policy although few appear to have calculated precisely how much extra time it gives them before plants are affected. Nor have they related this to the cost of improving the irrigation system.

4.1.3 Slab width

Slab width varied between 15 and 20 cms, principally as a result of volume needs. The 20 cm slabs perhaps became more common as growers moved towards the 'V' - system, in tomatoes, as many did not want to halve the substrate volume. However, more recently, substrate volumes have reduced further and most growers now use 15 cm wide slabs. Only 7.5% of growers used 20 cm slabs and this included all of the cucumber growers who responded.

4.1.4 Root distribution

Substrate manufacturers have made great efforts to construct slabs which would encourage rooting through as much of the substrate as possible so that plants become less vulnerable to localised damage, especially as a result of disease. They have also attempted to reduce the volume of root which develops along the underside in relation to elsewhere in the slab. This is because roots along the underside of the slab are more vulnerable to waterlogging if the water level rises or if exit slits become blocked.

It is not known how much the root which develops in various parts of the substrate contributes to overall water and nutrient uptake by the plant. The variation in the quantity of root per m^2 can be very large as demonstrated at Stockbridge House where microfiltration of recirculated water produced a heathy white mat of roots in contrast to a control with no treatment. However there were no differences in yield between these two treatments which suggests that most healthy crops produce more than enough root. While different types of substrate may lead to different patterns of root distribution, there is no evidence for any response in terms of yield or fruit quality.

However, increasing fruit loads may be putting extra strain on root systems, particularly towards the end of the season. It is not known where in the root mat water and nutrients are absorbed. However where this occurs has relevance to the appropriate moisture, air and nutrient levels in those areas.

4.1.5 EC Control

Producers have been concerned for some time at the large volumes of water and fertilizer that are wasted in attempts to reduce EC levels in slabs. Manufacturers have not yet provided convincing evidence that any particular product reduces the need for such 'flushing out'. Growers are increasingly using the EC of drain water rather than samples collected from the slab for monitoring and some limited control of irrigation. However it is not clear to which parameter, applied, slab or drain EC plants are most responsive.

4.2 Irrigation practice

4.2.1 Growing System

The trend for the adoption of the V system in tomato crops has two major implications for irrigation practice. There is a 50% reduction in substrate volume, and potentially therefore water holding capacity, per unit area of crop. At the same plant population there are double the number of drippers per m^3 of substrate.

Because of the reduced substrate volume some growers have been inclined to increase irrigation frequency but to reduce applied volume per application. Application volume has been reduced to 70-100 mls per dripper in a number of cases, especially where more freely drained rockwool and glasswool materials have been adopted. This policy may have a number of negative implications.

* An increased variation in dripper output is likely to result, especially where a limited number of cycles is required per day because of drain-back from the system and the need for it to refill.

* Control of root zone conductivity may be affected because of the effect on flushing of the medium and root aeration may also be reduced.

4.2.2 Plant Population

There is a continuing trend to reduce initial plant populations with tomatoes but to increase spring and summer densities by retaining additional sideshoots. This has proved very effective in regulating fruit size through the season. The combination of higher summer densities and increased CO_2 enrichment rates has enabled substantial yield increases to be achieved whilst improving summer fruit quality at the same time. Lower initial plant densities have given bigger and better quality fruit in the early season.

Survey results showed the average starting population in 1996 to be 2.02 plants/m2 (8175/acre) rising by 68% with additional shoots to 3.40/m2 (13760/acre). There are a number of implications with regard to irrigation practice.

* It has been customary for growers to compare irrigation application on a per plant basis. The water requirements of the crop on an area basis depend primarily on canopy light interception and there is no reason to suppose this will be different for a canopy comprising individual plants compared with one formed from multi-headed plants. The water application system in terms of dripper numbers per unit area may be different however.

As plant populations are increased by taking additional sideshoots it is very important to consider and compare irrigation requirement and application on an area basis rather than a plant basis. The water requirement per m^2 should be divided by the number of drippers per m^2 to give the desired application volume per dripper not per "plant".

* Reduction of initial plant numbers with existing irrigation systems will result in there being "spare" drippers. If the spare drippers are removed the maximum capacity of the system on an area basis per hour will be reduced proportionately. If the drippers are retained their positioning has to be considered.

4.2.3 Dripper Position

In a substrate grown crop, if the spare drippers are placed between the plants to wet up the slabs before planting or immediately afterwards, there is a risk of the plants receiving insufficient water. Because the drippers placed in the slabs are at a lower point than those in the plant cubes, there is some evidence of an unexpectedly large difference in output between drippers with those supplying the plants delivering less than those between the plants because of drain-back and or pressure differences.

Because plants at lower initial populations are further apart it seems logical however to place spare drippers between the cubes when the roots are fully established, as long as the drippers are not directly above drainage slits. This should give more even conditions through the substrate.

A recent development which has placed further emphasis on this area has been the propagation of two plants in a single cube. In the survey, 33% of tomato growers used this technique in 1996 and it is known that there has been a further increase in 1997. The technique is particularly relevant to production in the V system and offers significant cost savings. It results in more "spare" drippers per cube however which could be positioned on the cube or elsewhere on the slab. Such positioning may have an impact on the moisture, aeration and EC in different parts of the slab. However some growers are now investing in a smaller number of drippers of higher capacity (4l/hr) to save costs and hence will not have spare drippers. Dripper positioning by survey respondents are shown in Table 3.

Table 3. Positioning of drippers by survey respondents

	Percentage of total number of drippers		
	On the Block	**Between Blocks**	**End of Module**
Tomatoes	81%	15%	4%
Cucumbers	93%	7%	0%
Peppers	100%	0%	0%
All Crops	83%	14%	3%

4.2.4 Module Drainage

Although not covered in the survey, the way in which drainage slits are made in module wrappers is believed to be of underestimated importance. The positioning of drainage slits by survey respondents are listed in Table 4.

Table 4. Positioning of drainage slits by survey respondents

	Drainage Slit Position - % of respondents			
	Under Block Only	Between Blocks Only	End of Module Only	Between Blocks And End of Module
Tomatoes	4	71	8	17
Cucumbers	0	100	0	0
Peppers	0	0	0	100
All Crops	3	75	9	13

There have been problems where slits have been made on the upslope side of the slab instead of the downslope side. Slab wrapping can effect how water moves out of the slab. Problems may also occur where roots are able to grow out into the drains with potential risks of disease (i.e. Pythium).

Where drainage is impeded because slits are not made to the bottom of the wrapper or the wrapper moves around the slab later in the season because of the sideways pull of plants, there is believed to be an increased risk of root related problems such as blossom end rot in tomatoes and peppers. An increasing number of cases of BER have been observed where drainage is impeded in this way.

Higher slab conductivity levels have also been recorded where wrappers have not been slit to the bottom. Whether BER is related to reduced root aeration, especially at night, increased EC levels or both is not known and should be further investigated.

4.2.5 Water Source

Survey results are in Table 5. Since many growers use more than one water source, figures are expressed as a percentage of total supplies, not of individual respondents.

Table 5. Water sources used by survey respondents

	Water Source (% total supplies)		
	Mains	Borehole	Glasshouse Roof
Tomatoes	48	41	11
Cucumbers	33	67	0
Peppers	35	65	0
All Crops	44.6	47.6	7.8

The use of glasshouse roof water imposes greater risk of diseases such as Pythium (perhaps why it is less commonly used for cucumbers and peppers) and also causes complications in nutrient control, especially in hard water areas where the composition of roof water may be very different to mains supplies. The use of borehole supplies is increasing as the cost of mains supplies rises. Some borehole supplies have high levels of dissolved minerals, such as iron, which can cause blocking of irrigation nozzles without appropriate treatment and there are risks of slimes developing.

4.2.6 Crop Water Use

Annual Water Use

Grower records of water use for tomatoes for the 1996 cropping season are in Appendix 2. Comparisons are made between recirculated NFT systems and non-recirculated rockwool systems.

Average water use in NFT was 779 litres/m^2 for the full season and in rockwool 1381 litres/m^2. To account for the potential effects of variations in light receipt by individual growers, the water use was calculated per unit light receipt recorded by the same grower. Average use of NFT crops was 215 mls/MJ/m^2. Average application to rockwool crops was 353 mls/MJ/m^2.

Some grower records of drainage in run to waste systems have produced a figure of 300-400 litres/m^2/year. When deducted from the total application this has suggested an uptake of around 1000 litres/m^2. Either measurements of drainage from the rockwool crops have been consistently inaccurate or there are fundamental differences in uptake between NFT and run-to waste systems. It may be that water uptake in NFT is reduced perhaps as a result of inadequate oxygen for example. Comparisons of water use by NFT and rockwool grown crops at Silsoe have in fact found NFT crops to use more water than rockwool (Hamer in press). There is a need for research to determine how water uptake by crops grown in NFT and in rockwool systems vary and why.

If plant uptake in NFT and rockwool is in fact similar it indicates that the average irrigation volume applied to run to waste rockwool crops is 64% more than NFT crops. This equates to a drain or run-off percentage of 39% if the excess is calculated as a percentage of the total volume applied to the rockwool crop. This figure is higher than some growers believe they are achieving.

Short Term Water Use

Figures for water use for 4 weekly periods are also given in Appendix 2. Water use by NFT crops varies by a factor of 96% from 187 mls/MJ/m^2 in weeks 21-24 to 367mls/MJ/m^2 in weeks 01-04. Water application to rockwool crops varies by 81% from 300 mls/MJ/m^2 in weeks 21-24 to 543 mls/MJ/m^2 in weeks 01-04. Water use also varies significantly from day to day and within the day both in actual terms and in relation to light receipt.

Examples of water uptake on a single day in a commercial NFT system are given in Appendices

3 and 4. In the first example the water uptake per unit solar radiation varies by a factor of more than 15. Water uptake is significantly higher in the afternoon of sunny days than the morning.

This agrees with data from observations on NFT crops at Silsoe Research Institute (Grower, 12 May 1994). There is also a significant uptake of water at night.

Changes over a year and shorter term variation in water uptake indicate that control of irrigation application based solely on solar radiation measurement is potentially inaccurate. Other factors affecting water uptake need to be taken into account.

4.2.7 Irrigation System Control and Design

Practically all systems in the survey were controlled by computer. The average age of controller in 1996 was 7.4 years (7.3 tomatoes; 9.8 cucumbers; 3.3 peppers). The average age of irrigation distribution system was 4.8 years (4.5 tomatoes; 6.5 cucumbers; 3.5 peppers). 74% of drippers used were of the capillary stake type and 24% labyrinth types. Although more expensive there is an increasing trend towards the latter type especially those with pressure compensating drippers (i.e CNL). These appear to give better distribution accuracy by preventing drainage from the system between irrigation cycles, especially on slopes.

The accuracy of water distribution will become yet more important as water costs rise and attempts are made to minimise excess application of water and fertiliser for cost and environmental reasons.

System supply as in 58% of the cases surveyed came from one end of the row; 14% from both ends and 28% from a central point. Although the best arrangement will depend on row length, dripper type, system pressure and slope it should not be difficult to produce clearer advice in these areas. Although supply from both ends of the rows might be thought to give more even distribution it is possible that this is the worst arrangement because of the difficulty in equalising pressures down the row. Checks on irrigation distribution were made on an average of 2.3 occasions per year. The variation in dripper output was recorded by 55% of respondents only and the average figure quoted was 22%.

The average volume per dripper of applied solution per irrigation cycle per dripper was 149.8 mls (tomatoes 143; cucumbers 195; peppers 137).

Control of individual irrigation cycle was in 48% of cases by meters (litre counters) and 52% on a timed basis. Control on time is not recommended because of variations in flow rate as a result of pressure variations and progressive accumulation of material in filters.

Control of applied volume by litre counters has also been found to be inaccurate in a number of cases because of incorrect calibration either on installation or subsequently. One system tested was supplying a 50% greater volume than indicated.

Theoretical calibration factors are often programmed into the computer based on pump capacity, pipe sizes and pipe lengths. This is not sufficiently accurate and the calibration factor needs to be based on actual measurement of system output compared with the computer indicated figure.

Control of irrigation frequency was based in 88% of cases primarily on a time/light interaction ("cyclic" control). In 9% of cases application was triggered by start trays. Full control by drain measurement could be practised by 3% of growers but 27% had the facility to use drain management as a supplementary control mechanism to cyclic starts.

The survey revealed that the average time for starting and finishing irrigation is manipulated by growers with later starts and earlier finishes in relation to sunrise and sunset times in winter (Table 6).

Table 6. Number of minutes after sunrise that irrigation started and before sunset that irrigation ceased for survey respondents.

	Time after sunrise (minutes)			Time before sunset (minutes)		
	Winter	**Spring**	**Summer**	**Winter**	**Spring**	**Summer**
Tomatoes	56	44	44	77	76	65
Cucumbers	48	36	24	72	48	36
Peppers	56	44	44	77	76	65
All Crops	56	41	39	82	71	60

The survey also showed that a large number of growers use some night watering throughout most of the year (Table 7).

Table 7. Average number of night waterings used per day by survey respondents

	Winter	**Spring**	**Summer**
Tomatoes	0.52	0.58	0.79
Cucumbers	0.40	1.00	1.00
Peppers	0.52	0.58	0.79
All Crops	0.50	0.61	0.79

Where start trays are used and no restrictions applied to their operating time per day a significant number of night waterings are sometimes applied, especially with cucumbers. This accords with indications from water uptake monitoring in NFT systems.

4.2.8 Potential Control Functions

Control of irrigation frequency based primarily on solar radiation measurement is not particularly accurate as can be seen by the variation in uptake in NFT systems in relation to light over time, both in the short and longer terms. The effects of other factors, such as atmospheric humidity, need to be taken into account also.

A number of approaches could be taken to achieve better control.

Modelling

Computer models to link glasshouse environment to water uptake have been developed. There are however a number of limitations to this approach.

* Information is needed on factors such as crop light receipt for individual glasshouses to take account of glasshouse light transmission.

* Further developments in computer software are needed for it to be widely available for use by growers.

Monitoring of Plant Uptake

Monitoring of actual uptake by start tray systems appears to be attractive. The potential disadvantages are:-

* Relatively few plants are monitored and the siting of the trays to reflect average water use for the whole crop is a potential problem.

* There may be some advantage in restricting application under some conditions to affect growth or fruit development directly, or indirectly through slab aeration. The operation of the trays can be restricted on a time basis however.

* Root conditions in the trays may not be exactly the same as in normal modules because of effects on drainage, root zone conductivity and other factors.

Drain Management

This has proved reasonably effective in practice as a supplementary control mechanism to cyclic starts. Drainage can be relatively easily collected from many plants to give good sampling accuracy. Potential problems are:

* Measurement of drainage volume has not proved very accurate because of the unreliability of some of the equipment used and the effects of leaks from the system.

* Measurement of drain conductivity has proved more robust and is increasingly

commonly used as a back-up system to cyclic starts but may be affected by factors other than water requirement. An increase in substrate conductivity is commonly recorded in the afternoon of sunny days.

This may be because of insufficient water application when calculated on a light basis, as previously described, or the accumulation of excess nutrients which may not be needed by the plant under these conditions. Circumstantially, it would appear that a significant proportion of applied water, with its nutrient content, is used to control substrate conductivity. This may be to the disadvantage of substrate aeration.

It would be more logical to avoid excess nutrient application by relating it more accurately to nutrient uptake. If additional water is applied to match water uptake more accurately, the same total weight of nutrients could be supplied at a lower concentration to help avoid accumulation. More even substrate conductivities are also likely to have beneficial effects on fruit quality factors such as skin finish in tomatoes and peppers.

Evaporimeters

Automatic sensors with evaporating surfaces similar in character to leaf surfaces are of potential interest for better control. Sited in individual glasshouses these would reflect individual glasshouse conditions and their effects on water uptake.

Sensors would need to be robust and reliable and siting would be of obvious importance but it is surprising that there has not been more commercial interest in such possibilities.

Direct Control of Substrate Moisture Content

The potential advantages of controlling rockwool slab moisture content have been indicated in the Dutch experiments previously referred to. The development of a reliable and cost-effective active drainage system and moisture meter are a necessary requirement for such a system.

5. Key Areas for Improving Current Practice

1. Applied irrigation volume should be considered and compared on an area basis (per m^2) not on a per plant basis.

2. Applied irrigation volume per individual application should be measured by meters ("litre counters") not on a time basis.

3. Litre counters are frequently incorrectly calibrated both on initial installation and after subsequent changes to systems. Actual applied volumes should be measured and compared with computer setpoints to check calibration.

4. Few growers carry out regular checks on the variation in dripper output within systems. These would be of obvious benefit in picking up problems of blocked drippers at an early stage.

5. The capacity of some irrigation systems may not be sufficient to supply the needs of plants during the brightest hours of sunny days. The maximum light sum for an hour in June is likely to be around 3.5 MJ/m^2. Assuming water use of around 300mls/MJ/m^2 for a rockwool crop (from survey data, an irrigation system would need to be able to supply 1 litre/m^2/hour. In order to allow for reduced efficiency for whatever reason (i.e. leaks) spare capacity should be available in the system.

6. Existing irrigation control is based largely on solar radiation measurement and is not accurate for all conditions. This is because:-

   i) Solarimeters are seldom calibrated and frequently inaccurate.

   ii) A single measurement is made outside the glasshouse and therefore takes no account of variations in glasshouse light transmission.

   iii) Other factors such as humidity are important in determining transpiration

7. Incorporation of transpiration models in computer programs may incur similar problems to those in item 5 above but to a lesser degree.

8. In the short term, the use of drain monitoring systems (volume or EC) appears a useful back-up to time/light starts.

9. Careful attention to the positioning of drainage slits is necessary to avoid impeded drainage.

10. The use of two plant propagation cubes for tomatoes provides the opportunity to reduce dripper numbers, and therefore cost, per unit area as long as higher capacity drippers are used to ensure adequate application per m^2 per hour. This makes it yet easier to justify

more accurate, but more expensive, dripper systems.

11. The accuracy of distribution will become yet more important as efforts are made to reduce excess application which drains to waste. Current practice typically involves substantial excess application.

6. Future Research and Development

This review has highlighted a number of areas requiring increased focus for research.

6.1 Matching water supply to water demand

The current practice of controlling irrigation on the basis of solar radiation and time does not provide a close match of irrigation to the water requirements of plants and may lead to excess irrigation, particularly in dull weather. Improved control may be achieved through:

* The development and evaluation of control programs calculating predicted transpiration from environmental variables. Where uptake does not match theoretical predictions under certain conditions there is a need to investigate what factors might be preventing transpiration or water uptake.

* Development and evaluation of transpiration sensors for scheduling irrigation

* Evaluation of slab moisture sensors and slab weighing devices for scheduling irrigation

* Evaluation of drainage volume and EC for scheduling irrigation

* Evaluation of plant triggered start trays for scheduling irrigation

6.2 Water use by NFT and rockwool run to waste crops

Grower measurements of drainage volumes in run-to-waste systems when deducted from total application suggest that water uptake in rockwool crops is greater than in NFT systems or that drain volume measurement is inaccurate. This situation should be clarified and reasons for any differences investigated.

6.3 Influence of moisture in the root environment on crop yield and quality

There is a need to investigate the impact of irrigation regimes on the root zone environment and the role of the root zone environment and in particular moisture content and root aeration and fluctuations in these variables in determining subsequent crop growth, yield and fruit quality.

6.4 Influence of fluctuating ECs in the root zone

In addition to improving water supply to match plant needs there is an opportunity to optimise applied EC to create a stable root zone environment through the use of light and possibly time modulation. The effects of a more stable root zone EC may result in improved fruit quality and may result in less environmental pollution and savings on water costs as the practice of flushing out excess nutrients becomes unnecessary. However these hypotheses have yet to be tested and it is not known whether the EC of the applied feed solution, the drain solution or the solution within the slab or different parts of it are most important in terms of the plants response.

6.5 Transient plant wilting

Transient plant wilting and subsequent leaf scorch can occur when weather conditions change from dull to bright. The internal resistance to rapid water uptake when conditions change from dull to bright needs to be investigated further as if it can be overcome there may be benefits in terms of yield and fruit quality as well as prevention of leaf scorch.

Water uptake may lag behind transpiration losses due to the structure of the root system not having the capacity to take up sufficient water or because there are adhesion components within the water itself preventing rapid uptake. Alternatively new leaves developing in dull, humid conditions may be more permeable and loose water very rapidly when conditions change from dull to bright. Leaves grown under higher ECs in low light conditions are likely to have waxier cuticles and be less susceptible to water loss.

6.6 Variability in the distribution of water

Finally improvements in irrigation control can only be effective if the delivery system is accurate. The review of current commercial practice has shown that this has been a neglected area. The problem of drain-back and re-filling that causes differences in dripper output could be improved by using the Tichelmann system which is a circulatory system designed so that the route taken by water through the irrigation lines is equal for all supply lines. Such a system would result in a more uniform distribution of water (MACQU Project AIR3-CT93-1603 Annual Report 1995). The reduced variation in dripper output from such a system needs to be compared to variation due to age and type of dripper used. For example, CNL drippers may improve the accuracy of drippers. The effects of such developments on variability between drippers and ultimately on variability within the crop in terms of fruit size and quality need to be evaluated.

7. Conclusions

This review has identified a number of areas in which some growers could improve the efficiency of their irrigation systems through relatively simple changes in practice. The review has also identified areas requiring further research and development before further improvements are possible. Improved control and accuracy of supply of irrigation is likely to result in improved crop performance and also in reduced environmental pollution and savings on costs of water and nutrients in run-to-waste systems. However the greatest reductions in waste would result from the use of recirculation in substrate grown crops.

The main areas identified for further research and development were:

* Improving the match between water supply and water demand
* The roles of substrate moisture and aeration in determining growth, yield and quality
* The influence of fluctuating ECs in the root zone
* Factors affecting transient plant wilting
* Variability in the distribution of water

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Appendix 1. Grower Questionnaire

HDC Irrigation Survey 1996

The Horticulture Development Council has instigated a review of the Research and Development, and an Evaluation of current techniques used in the irrigation of tomatoes, cucumbers and sweet peppers grown in hydroponic systems. Its aim is to identify what, if any, further work is necessary. As part of the evaluation I am seeking technical information related to the different methods of irrigation currently in use.

This questionnaire attempts to identify those topics which are of greatest interest and I would be grateful for your co-operation in completing a copy for your business. Where you have more than one system / substrate please complete the form for the main system in use on the nursery. However we are particularly interested in seeing as many systems as possible. Consequently we would be very grateful if you completed a second questionnaire for any that is substantially different.

Name:

Address:

Crop: Tomato / Cucumber / Sweet Pepper

Substrate

Type: Rockwool   Polyurethane Foam   Glasswool   Perlite   NFT

Manufacturer:

Product Name:

Slab dimensions: Height:
Width:
Length:
Distance between:

Age of slab: % New......% 1 Year old......% 2 Years old......% Over 2 Years old......

Plant Density

Row System: Double row / V system

Block System: Single plant / Double plant

No. of plants per module:

No. of heads per module (maximum):

Total plant population (heads / m2 glasshouse area):

Water Supply

Source: Mains……% Borehole……% Glasshouse roof water……%

Irrigation Control System (Computer)

Manufacturer:

Model:

Age:

Irrigation Distribution System (dripper system)

Manufacturer:

Product Name:

Age:

Drip nozzle Rate (litres / hour):

System Pressure (bar):

System Capacity (litres/drip nozzle/hour):

System Supply Design (in rows):From one end / From both ends / From a central point

Drip Nozzle Distribution (No of nozzles per module):

1. On the block ……
2. Between blocks ……
3. At the end of the module ……

Slit distribution (No per module):

1. Under the block ……
2. Between the blocks ……
3. At the end of the module ……
4. Unwrapped module ……

Maintenance of the Irrigation System

1. Frequency of check for variation in the drip rate between nozzles (times/year):
2. Variation in drip rate recorded (%):
3. Techniques used for unblocking nozzles during season:
4. Techniques used for unblocking nozzles at the end of the season:

Irrigation Application Technique

Volume Application Control Method:

Based on: Litre counter / Time Controller

Irrigation trigger system	*Rate*
Time	……mls/dripper/start after……hours
Light	…… mls/dripper/start after……MJ/m2
Time / Light (Cyclical)	
Interval between starts	……minutes
Reduction in pause time with light	……minutes
Start tray	……litres/m2 after……litres/m2 evaporated

Drain Control System

Is the system used as a full control?	Yes / No
Is the system used as a supplementary system?	Yes /No
Drain	Minimum % drain……
EC	Maximum EC……mS
Manual Starts	Yes / No
Response to Drain Control Trigger:	
1.Extra Starts / Standard Volume	Yes / No
2.Increased Volume per start	Yes / No

Day / Night Watering Practice

No of hours after sunrise that irrigation is started

1. winter ……hours
2. spring……hours
3. summer……hours

No of hours before sunset that irrigation is stopped

1. winter ……hours
2. spring……hours
3. summer……hours

Frequency of night watering	*Volume applied*
1. winter……times	……..mls / dripper
2. spring……times	……..mls / dripper
3. summer……times	……..mls / dripper

Comments on Irrigation Technique not covered by questionnaire(continue overleaf):

Appendix 2. Water use in NFT and rockwool in 1996

	45-48	49-53	01-04	05-08	09-12	13-16	17-20	21-24	25-28	29-32	33-36	37-40	41-44	TOTAL
	WEEK NUMBERS													
NFT														
GROWER SOLAR RADIATION (MJ/m²)														
A	75	45	48	102	199	367	440	594	446	515	397	251	161	3640
B	76	46	51	109	176	306	446	543	500	512	359	265	153	3542
C	77	55	48	114	175	307	447	559	522	525	405	275	160	3669
AVE	76	49	49	108	183	327	444	565	489	517	387	264	158	3617 (1)
WATER USE (litres/m²)														
A	0	2	14	35	50	75	93	113	107	125	104	73	34	825
B	0	12	20	36	43	63	83	102	113	115	90	58	30	765
C	0	6	19	35	49	64	82	103	107	114	90	54	24	747
AVE	0	7	18	35	47	67	86	106	109	115	95	62	29	779 (2)
ml/MJ/m²	0	142	367	324	256	204	193	187	222	222	245	234	183	215 (3)
ROCKWOOL														
SOLAR RADIATION (MJ/m²)														
D	78	50	53	107	229	386	466	609	472	574	405	272	139	3840
E	81	52	51	110	209	390	455	605	468	534	407	275	175	3812
F	103	61	72	129	262	386	486	630	588	624	518	308	189	4356
G	71	52	55	124	198	328	472	582	474	558	426	276	166	3782
H	88	53	61	137	197	364	486	593	524	578	445	303	164	3993
I	71	53	59	123	195	334	450	571	462	565	462	282	179	3806
J	83	53	51	114	217	307	484	539	510	553	433	292	149	3785
AVE	82	53	57	121	215	356	471	590	500	569	442	287	166	3909 (4)
WATER USE (litres/m²)														
D	0	16	17	47	98	136	163	199	175	179	167	116	22	1335
E	1	9	40	81	108	140	195	152	258	217	168	121	21	1511
F	0	0	29	58	103	171	190	164	174	207	202	155	42	1495
G	0	0	26	51	82	131	143	174	173	205	171	106	27	1289
H	2	14	32	67	96	132	163	201	176	198	160	93	32	1366
I	0	20	37	66	82	104	133	167	168	193	160	112	61	1303
J	2	16	34	63	88	118	170	185	141	216	199	120	16	1368
AVE	1	11	31	62	94	133	165	177	181	202	175	118	32	1381 (5)
ml/MJ/m²	0	207	543	512	437	373	350	300	362	355	395	411	192	353 (6)

% excess	**0**	**45**	**48**	**58**	**71**	**83**	**81**	**60**	**63**	**60**	**61**	**76**	**5**	**64 (7)**
%run-off	**0**	**31**	**32**	**37**	**41**	**45**	**45**	**38**	**39**	**37**	**38**	**43**	**5**	**39 (8)**

Key: (3) = (2) ÷ (1) x 1000 (6) = (5) ÷ (4) x 1000

(7) = (6) - (3) ÷ (3) x 1000 (8) = (6) - (3) ÷ (6) x 100

Appendix 3. Water use in NFT and rockwool in 1995

	WEEK NUMBERS													
	45-48	49-53	01-04	05-08	09-12	13-16	17-20	21-24	25-28	29-32	33-36	37-40	41-44	TOTAL
ROCKWOOL														
1/m^2	13	19	37	60	99	128	160	163	212	218	167	100	31	1407
MJ/m^2	62	66	63	132	293	399	508	512	633	576	421	279	179	4123
ml/MJ/m^2	209	288	587	455	338	321	315	318	335	378	397	358	173	341
NFT GROWER														
1/m2	0	9	23	34	52	67	83	81	107	110	81	53	20	720
MJ/m^2	62	54	59	121	272	376	464	446	553	549	387	254	173	3770
ml/MJ/m^2	0	167	390	281	191	178	179	182	193	200	209	209	116	191

Appendix 4. WATER USE IN NFT EXAMPLE   DATE 19.8.96

TIME Hrs	TEMP	RH	CO2 vpm	LIGHT SUM J/cm^2	WATER USE l/m^2	WATER USE $ml/MJ/m^2$
06.00	23.0	73	1149			
07.00	23.1	74	1162	7	0.0013	18
08.00	23.7	77	666	61	0.0124	20
09.00	25.1	77	666	104	0.0312	30
10.00	26.7	76	564	164	0.0696	42
11.00	27.3	73	512	206	0.1644	79
12.00	27.6	70	466	199	0.3280	164
13.00	28.2	67	391	242	0.3727	154
14.00	28.9	65	410	254	0.4600	181
15.00	29.3	60	398	231	0.5309	229
16.00	29.1	62	478	178	0.5673	318
17.00	29.4	59	454	130	0.4238	326
18.00	28.6	52	460	108	0.3060	283
19.00	28.0	44	494	86	0.2715	315
TOTAL				1970	3.5930	182
19.00-06.00						0.9362 (*)
TOTAL				1985	4.5293	228

(*) 20.6% of 24 hour total

Appendix 5. WATER USE IN NFT EXAMPLE DATE 22.8.96

TIME Hrs	TEMP	RH	CO2 vpm	LIGHT SUM J/cm^2	WATER USE 1/m^2	WATER USE ml/MJ/m^2
06.00	20.9	76	1141			
07.00	22.1	80	949	6	0.0382	64
08.00	22.2	84	776	58	0.0564	88
09.00	23.7	85	639	78	0.1555	199
10.00	24.6	83	564	159	0.1945	122
11.00	26.0	81	497	203	0.4255	209
12.00	24.5	80	588	216	0.2891	133
13.00	25.4	78	474	125	0.3109	248
14.00	25.1	79	482	164	0.3045	185
15.00	26.2	74	465	175	0.2700	138
16.00	26.9	71	442	155	0.4264	275
17.00	26.8	67	399	103	0.3527	342
18.00	25.7	64	472	134	0.2782	207
19.00	26.0	54	538	103	0.1945	188
20.00	24.9	59	847	85	0.1582	186
TOTAL				1661	3.5930	210
20.00-06.00						0.7400 (*)
TOTAL				1796	4.2351	236

(*) 17.4% of 24 hour total

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