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The results and conclusions in this report are based on a single experiment. The conditions under which the experiment was carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

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PRACTICAL SECTION FOR GROWERS

BACKGROUND, SCOPE AND OBJECTIVES

Improvements to irrigation control for long season tomato crops are likely to result in improved crop growth, yield and fruit quality whilst at the same time minimising the excessive use of water and nutrients. Accurate irrigation management is therefore vital in order to maximise productivity.

The recent findings of HDC project PC 119 (Fussel *et al.,* 1997) suggest that, from grower's measurements, water uptake of rockwool grown tomato crops is significantly greater than that of crops grown in NFT. These findings are based on growers calculations using applied and drainage / runoff volumes.

Data from Silsoe Research Institute (Hamer, 1998) contradicts these findings and reports that NFT crops may use more water than rockwool grown crops. Fussel *et al.* (1997) suggest that these discrepancies may be as a result of inaccuracies in drain volume measurement by growers.

In light of this contradictory information, there is obviously a need to determine whether there is a consistent difference in water uptake by crops grown in NFT and on a rockwool substrate. If significant variation in water use between these systems is observed, the factors contributing to this difference will also need to be identified. This will enable the development of more advanced irrigation control strategies aimed at maximising productivity of high quality fruit whilst minimising runoff and fertiliser usage.

The amount of runoff can be reduced considerably by closely matching the irrigation water applied to the crop to meet the requirements for transpiration and crop growth (this is normally small compared to transpiration). The widespread practice in the UK tomato industry is to use solar radiation (SOLAR) to predict the irrigation need together with timed starts at night and under low light conditions.

The accuracy of prediction can be improved by taking into account both solar radiation and vapour pressure deficit (S + VPD). Recently scientists at Silsoe Research Institute have developed an improved method to predict water uptake from tomato crops, which is based on the well known Penman-Monteith equation (SRI – PM). The equations used to predict crop water use are referred to as models. This latest model has yet to be evaluated in a commercial crop. Furthermore, the model needs to be compared with existing models to determine whether the accuracy of irrigation is improved.

As with the majority of irrigation models the latest model was developed using water use data from NFT grown crops. As well as to validate models there is a need to determine whether models developed for NFT systems are applicable for tomato crops grown in rockwool.

The main objectives of the two projects PC 142 and PC 151 were:

- to accurately measure and record the water use of a long season tomato crop grown in a re-circulated NFT system and in a rockwool run-to-waste system and therefore to provide detailed data in a suitable format that can be used to validate and compare irrigation models

- to compare recorded rates of water usage with values simulated by models based on (a) solar radiation, (b) both solar radiation and VPD and (c) the SRI model based on the Penman-Monteith equation.

- to identify any differences in water use for long season tomato crops grown in NFT and rockwool run-to-waste systems.

- to assist in validating the extrapolation of NFT derived water use models to other hydroponic systems.

SUMMARY OF RESULTS

The tomato crop, *cv* Espero, was planted on 27 March 1998 in a modern Venlo glasshouse at HRI Stockbridge House, comprising of four double rows of NFT alternated with four double rows of rockwool. Crop water use was measured from the beginning of August (week 31) to the end of October (week 43).

For the model validation, the crop water use data were divided into four periods at approximately three-weekly intervals comprising of three weather patterns and subdivided into 'night', 'morning' and 'afternoon periods'.

There were no significant differences in water use between NFT and rockwool grown crops. These findings support those of Hamer (1998). The potential for large inaccuracies in the measurement of flow / drainage volumes on rockwool run-to-waste systems was also illustrated.

The SOLAR model considerably overestimated crop water use during periods of high radiation. The overestimate was greater in the mornings than the afternoons. During dull periods the SOLAR model would not supply sufficient water for irrigation and at night no water would be applied even though there is a substantial requirement.

The S + VPD model underestimated water use by about 30% in August under moderate light levels and as the season progressed the accuracy of prediction increased so that by the end of the season the model underestimation reduced to about 10%. These underestimates were consistent for both the morning and afternoon periods. The S + VPD model was the most accurate prediction of water requirements at night particularly from September onwards.

The SRI - PM model was the most accurate of the three models in predicting crop water use during day light hours. However, there was an underestimation in water use in August and an overestimation in October. At night, there was a slight overestimation of water use in August and this overestimation increased with time so that by the end of October the estimation of water was nearly twice that required by the crop.

At night crop water use averaged 0.057 $l/m^2/h$ during August and reduced with time so that by the end of the experiment in October the crop water use averaged 0.047 $l/m^2/h$. These values compare with crop water use at night in the middle of the summer of about 0.07 $l/m^2/h$. Differences are probably due to the water requirements for crop growth rather than transpiration.

Overall growth habits of the two crops were similar, especially in respect to leaf length, leaf width and stem diameter. However, when the plants were assessed for vigour the rockwool grown crops had significantly higher vigour scores until late in the season (week 41).

Total fruit yields were significantly higher for the rockwool grown crop in this experiment but this was influenced by the fact that the third truss had to be removed from the NFT crop in early June (week 23), to redress the generative : vegetative balance of the plants as a result of the late sowing date and weather conditions. Previous HDC funded work has demonstrated that NFT grown tomato crops are capable of producing yields equivalent to, or higher than, Rockwool crops (see HDC projects PC 23a and PC 83).

ACTION POINTS FOR GROWERS

- Water use in NFT crops was shown to be similar to that of rockwool grown crops.

- The large discrepancies between water use in NFT and rockwool grown crops reported by Fussel *et al.* (1997) are probably attributed to inaccurate drain volume measurement. Runoff collection systems should be designed in order for realistic and meaningful data collection. The system should be maintained and checked regularly throughout the season.

- For the period under investigation (August to October) and in modern houses assuming a light transmission of 0.65, the crop water requirements as predicted by the SOLAR model equation, equate to irrigation applications of 150 ml/m^2 per light integral of 100 J/cm^2 plus an additional 50 ml/m^2 per hour. This suggests that irrigation scheduling should include timed starts in addition to applications based on light integral. This compares to current grower practice of either timed starts or irrigation when the light integral reaches a predetermined level. Further investigations are needed to provide information for the main earlier period of cropping.

- Although the SRI model accurately predicted crop water requirements during the day-time, the model needs to be revised for night-time use. Development is needed to provide software for either existing commercial irrigation controllers or those based on a PC.

PRACTICAL AND FINANCIAL ANTICIPATED BENEFITS

A better understanding of water use in crops grown in both NFT and Rockwool systems will assist in the development of more closely tailored irrigation strategies that will improve cost efficient production by reducing both fertiliser and water costs.

There are also ever increasing pressures placed upon growers, by customers and through direct legislation, to consider any effects their production systems may have on the environment. Production systems which are seen to be more environmentally friendly are likely to benefit from greater consumer acceptance. Moreover, in run-to-waste systems particularly, more accurate irrigation will mean that there is less runoff which will therefore reduce the risk of pollution of controlled waters.

The availability of an accurate model will enable the effects of any future changes in irrigation and feeding strategies, either through increased knowledge or by legislation, to be evaluated prior to implementation.

SCIENCE SECTION PC 142

INTRODUCTION

In the UK most protected hydroponic salad crops are produced using 'open' systems in which water and nutrients are applied in excess of the requirements of the crop. The surplus (runoff) is frequently lost and can lead to environmental damage. Irrigation can be applied either by using 'start trays' or estimating crop water use by models. The latter is in widespread use throughout the UK tomato industry in which crop water use is predicted as a proportion of the outside solar radiation. An empirical constant takes account of the transmissivity of the greenhouse, the proportion of solar radiation used for transpiration and a 'crop' factor estimated by the grower from observation of crop development. Solar radiation is measured, integrated over time and the empirical constant applied. When the result of this calculation reaches a fixed value, a fixed volume of water is applied. The fixed values are determined by the grower from visual observation of the crop and used in combination with timed starts so that irrigation is applied at night and under low light conditions.

The amount of runoff can be reduced considerably by closely matching the irrigation water applied to the crop to meet the requirements for transpiration and crop growth (this is normally small compared to transpiration). In substrate (soiless) systems the frequency of irrigation can be high, with several applications per hour when transpiration is high. The use of solar radiation alone to predict the irrigation need is bound to be inaccurate in the short term because of the sudden changes in the environment inside the greenhouse induced by climate control equipment. Furthermore, during the night using timed starts can lead to inaccuracy due to change in the vapour pressure deficit (VPD), a term that describes the dryness of the atmosphere.

An improvement in the accuracy of prediction of the irrigation requirement of a crop (I) can be obtained by taking into account both solar radiation (solar) and VPD in a simple formula (e.g. $I = a \times \text{solar} + b \times \text{VPD}$ where a and b are constants). Movement of water vapour by diffusion out of the leaf is controlled by the difference in the concentration of vapour inside and outside the leaf. The aperture of the stomatal pores through which the water escapes to the atmosphere changes with light level. The 'b' term is not a constant since it varies with the light levels. Thus the apparently simple formula becomes complex. Silsoe Research Institute has developed an improved formula (a model) for predicting crop water requirements. This is based on the well known Penman-Monteith equation for determining the energy requirements for transpiration. The model was developed from measurements of crop water use over a season and requires measurements of solar radiation, air temperature and relative humidity. The model has been used to irrigate an experimental tomato crop from February to May. The model accurately predicted the crop requirement for irrigation. This model has yet to be evaluated in a commercial crop to establish whether it improves the accuracy of irrigation compared to existing irrigation models. In this report three models for predicting the irrigation requirements are compared to the water used by a commercial long-season tomato crop grown in NFT (see science section PC 151 of this report). An assessment is made of the potential of the model for controlling the irrigation of a commercial crop.

MATERIALS AND METHODS

A full description of the experimental layout and method of measuring crop water use are presented in the science section - PC 151 of this report. The incoming global solar radiation (S_i, W/m^2) on a horizontal surface inside the greenhouse was measured by two Kipp and Zonen solarimeters which were located above the crop wires, 45 cm below the height of the gutter. A sensor, which combined the measurement of relative humidity and temperature (a monolithic humidity sensor with a precision platinum resistance thermometer - Model IH-3602-C from BFI Ibexsa Electronics Ltd, Aylesford, Kent), was mounted in the ventilated screen. The sensor measured RH to an accuracy of ± 2% and air temperature to ± 0.2°C. Unfortunately the humidity sensor failed on 24 August and the data were replaced from the measurements of RH recorded on the PRIVA environmental control computer (Priva UK Ltd, Tewkesbury, Glos).

The sensors were scanned very frequently, logged every ten minutes and downloaded weekly into a spreadsheet (MS Excel). The data were plotted and summaries enabled any problems to be identified and rectified. Data collection started during week 31 in 1998 and ceased at the end of week 43. Three-day periods of data were identified to represent a range of weather patterns on four occasions, at approximately three weekly intervals. The selection process also took into account whether the data was considered to be accurate (by comparing crop water use data from the NFT and rockwool grown crops) and the availability of data required as input to the models.

Water use (WU, l/m^2/h) of the crop grown in NFT was compared with model estimates based on:

a) Solar radiation (SOLAR):

$$WU = 3.6\,S_i / \lambda$$

Where λ is the latent heat of vaporization of water.

This is equivalent to an irrigation regime of *ca.* 100 ml per plant per 100 J/cm^2 incident radiation measured by an externally mounted solarimeter and a density of 2.7 plants/m^2.

b) Combination of solar radiation and vapour pressure deficit (S + VPD) from an expression given by Jolliet and Bailey (1992):

$$WU = 0.0036(0.141\,S_i + 28.1\,VPD)$$

where VPD (kPa) is vapour pressure deficit.

c) The SRI model based on the Penman-Monteith equation (SRI - PM):

$$WU = \frac{3.6}{\lambda}\left[\frac{\Delta\, i\, S_i + \left(\rho\, C_p / r_a\right) VPD}{\Delta + \gamma\left(1 + r_c / r_a\right)}\right]$$

where λ is the latent heat of vaporization of water, Δ is the slope of the saturation vapour pressure/temperature curve, ρ is the density of air, i is the radiation intercepted by the crop canopy, C_p is the specific heat of air, r_c is the canopy resistance to vapour transfer and r_a is the aerodynamic resistance. Hamer (in press) derived values for these variables for the long season tomato crop. The constant and λ convert energy units to the same units used for measuring crop water use ($l/m^2/h$).

Model estimates of crop water use were derived from 10 minute environmental data and hourly summaries produced. The data were subdivided into 'night', 'morning' and 'afternoon' with the night period being identified from the global radiation data ('night' when $S_i < 5$ W/m^2) and morning and afternoon ended and started at noon.

Four periods of the recording season were identified for three weather patterns (sunny, variable and cloudy) at approximately three weekly intervals.

RESULTS

Table 1 presents the daily values of environmental variables and the daily crop water used by the NFT grown crop and estimated by the models for the four periods.

Figures 1 - 4 present the time trend of crop water use (on an hourly basis) from measurements and estimates from the three models.

Figures 5 - 8 compare modelled and measured crop water use for the data separated into night, morning and afternoon periods. The line was fitted by linear regression and the coefficients of the regression are presented in Table 2. A further linear regression, with the intercept constrained through the origin, was fitted to the data (Table 2).

Table 1. The mean daily global solar radiation measured outside (S_o) and inside (S_i) the greenhouse (S_i was determined from the mean of two sensors), mean air temperature (T_a). mean relative humidity (*RH*) and daily crop water use measured (*WU*) and predicted from the three models (SOLAR, S + VPD, SRI - PM) for four periods in 1998

a) Period 1 - week 34

Date	S_o (MJ/m^2/d)	S_i (MJ/m^2/d)	T_a (°C)	*RH* (%)	*WU* (l/m^2/d)	SOLAR (l/m^2/d)	S + VPD (l/m^2/d)	SRI - PM (l/m^2/d)
19 Aug	19.9	12.3	22.0	81	4.02	5.02	3.03	4.05
20 Aug	4.5	3.0	21.0	87	2.03	1.20	1.22	1.78
21 Aug	17.2	10.3	21.5	83	3.73	4.23	2.55	3.34

b) Period 2 - week 37

Date	S_o (MJ/m^2/d)	S_i (MJ/m^2/d)	T_a (°C)	*RH* (%)	*WU* (l/m^2/d)	SOLAR (l/m^2/d)	S + VPD (l/m^2/d)	SRI - PM (l/m^2/d)
11 Sep	13.7	8.1	20.4	75	3.04	3.30	2.65	3.79
12 Sep	12.1	6.3	19.2	76	2.62	2.59	2.23	3.27
13 Sep	12.1	7.2	19.5	76	2.62	2.93	2.33	3.33

c) Period 3 - week 40

Date	S_o (MJ/m^2/d)	S_i (MJ/m^2/d)	T_a (°C)	*RH* (%)	*WU* (l/m^2/d)	SOLAR (l/m^2/d)	S + VPD (l/m^2/d)	SRI - PM (l/m^2/d)
30 Sep	1.5	1.0	19.0	83	1.44	0.42	1.04	1.76
1 Oct	5.5	3.7	19.1	81	1.87	1.53	1.57	2.35
2 Oct	3.6	2.4	18.3	80	1.72	0.96	1.33	2.13

d) Period 4 - week 43

Date	S_o (MJ/m^2/d)	S_i (MJ/m^2/d)	T_a (°C)	*RH* (%)	*WU* (l/m^2/d)	SOLAR (l/m^2/d)	S + VPD (l/m^2/d)	SRI - PM (l/m^2/d)
23 Oct	5.5	2.9	19.2	78	1.71	1.17	1.57	2.48
24 Oct	1.0	0.6	17.2	79	1.19	0.24	1.07	1.93
25 Oct	6.4	3.6	18.1	78	1.79	1.47	1.61	2.50

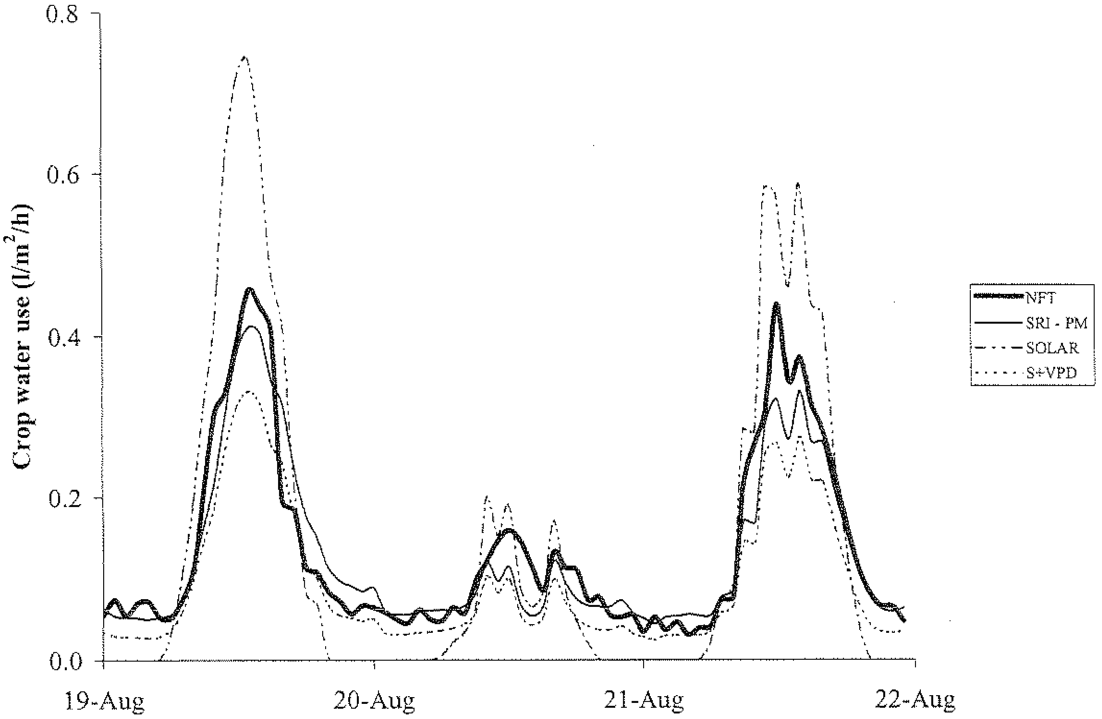


Figure 1. Period 1: Diurnal crop water use measured in the NFT grown crop and modelled

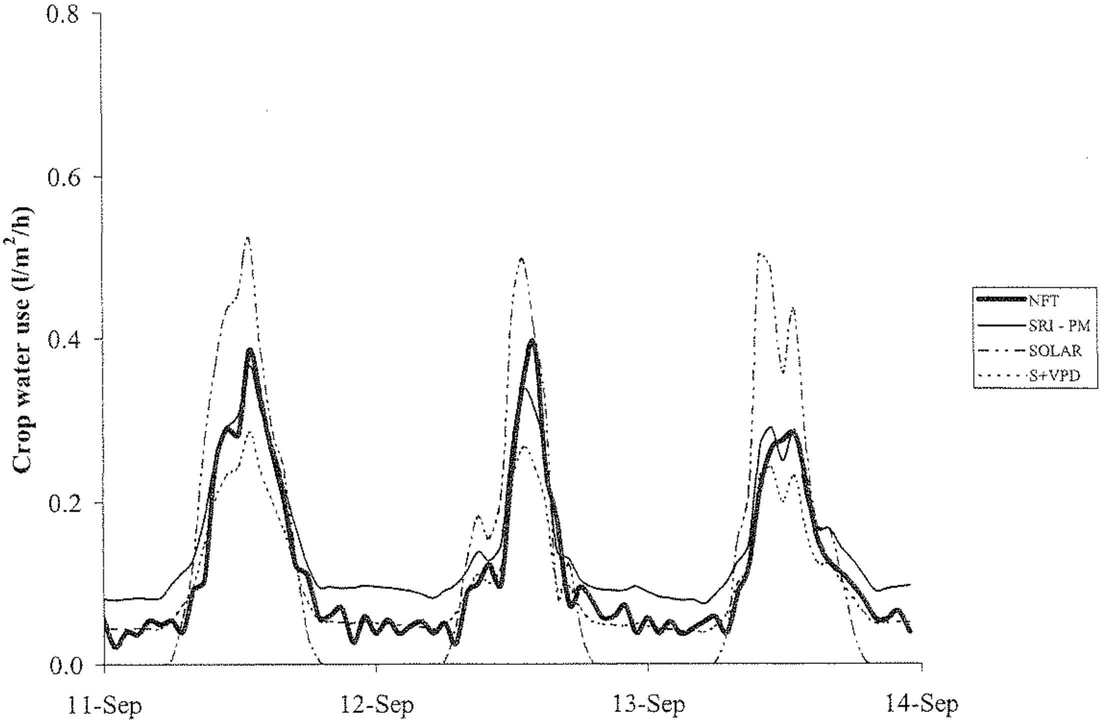


Figure 2. Period 2: Diurnal crop water use measured in the NFT grown crop and modelled

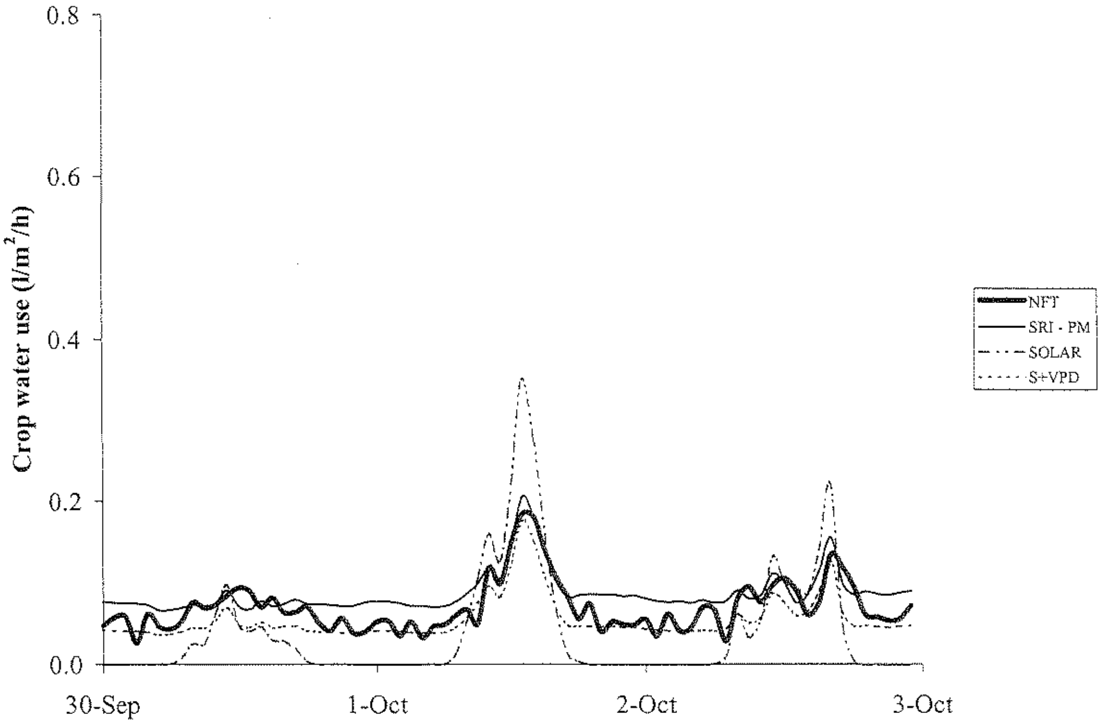


Figure 3. Period 3: Diurnal crop water use measured in the NFT grown crop and modelled

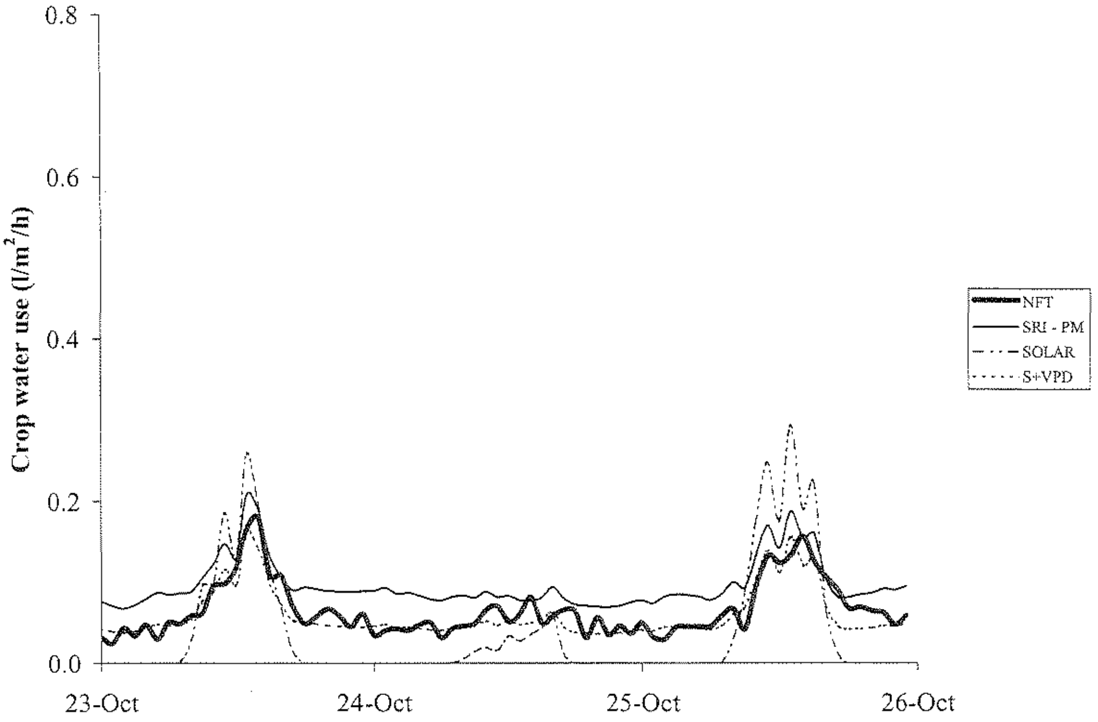


Figure 4. Period 4: Diurnal crop water use measured in the NFT grown crop and modelled

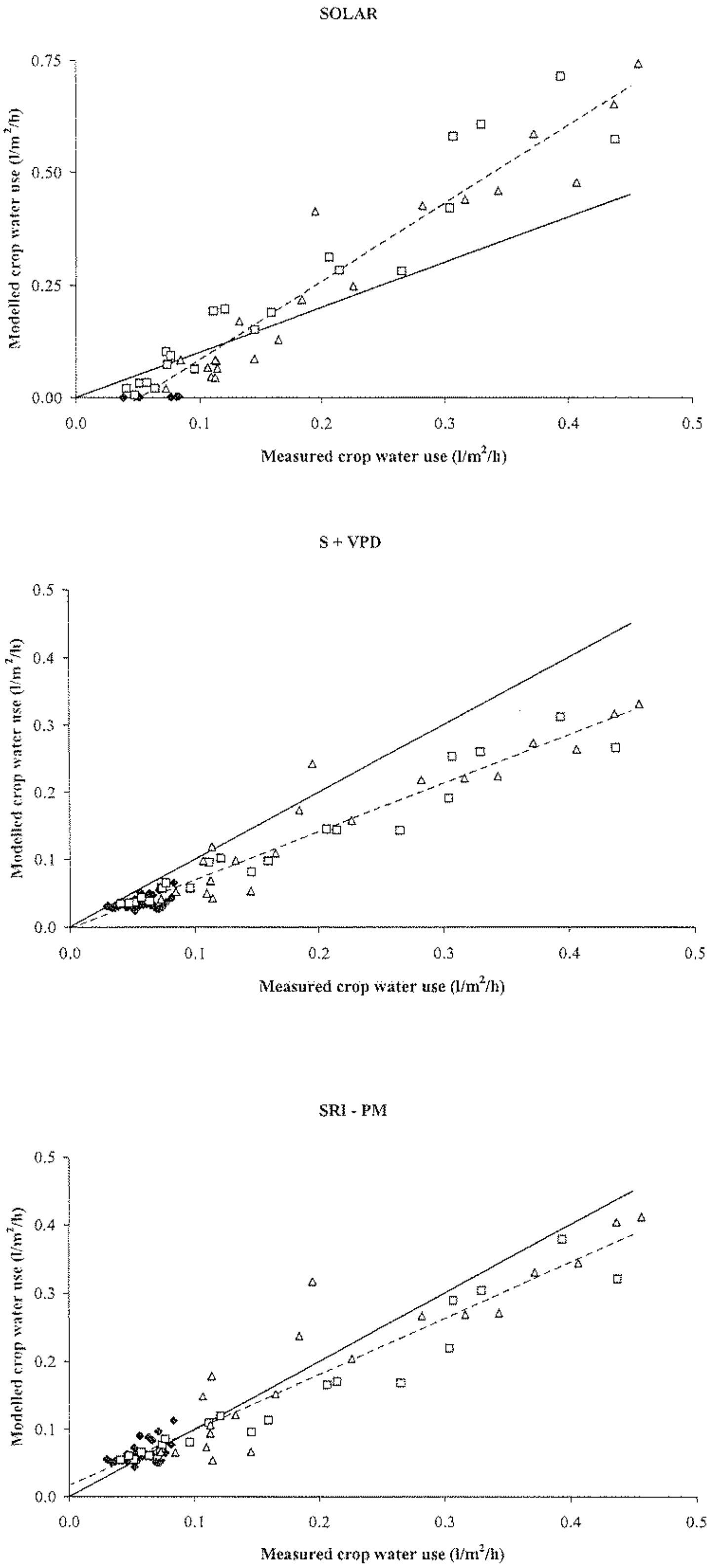


Figure 5. Period 1: Comparison of modelled and measured crop water use. = night, = morning, = afternoon, —— = 1:1 line; - - - - = fitted line

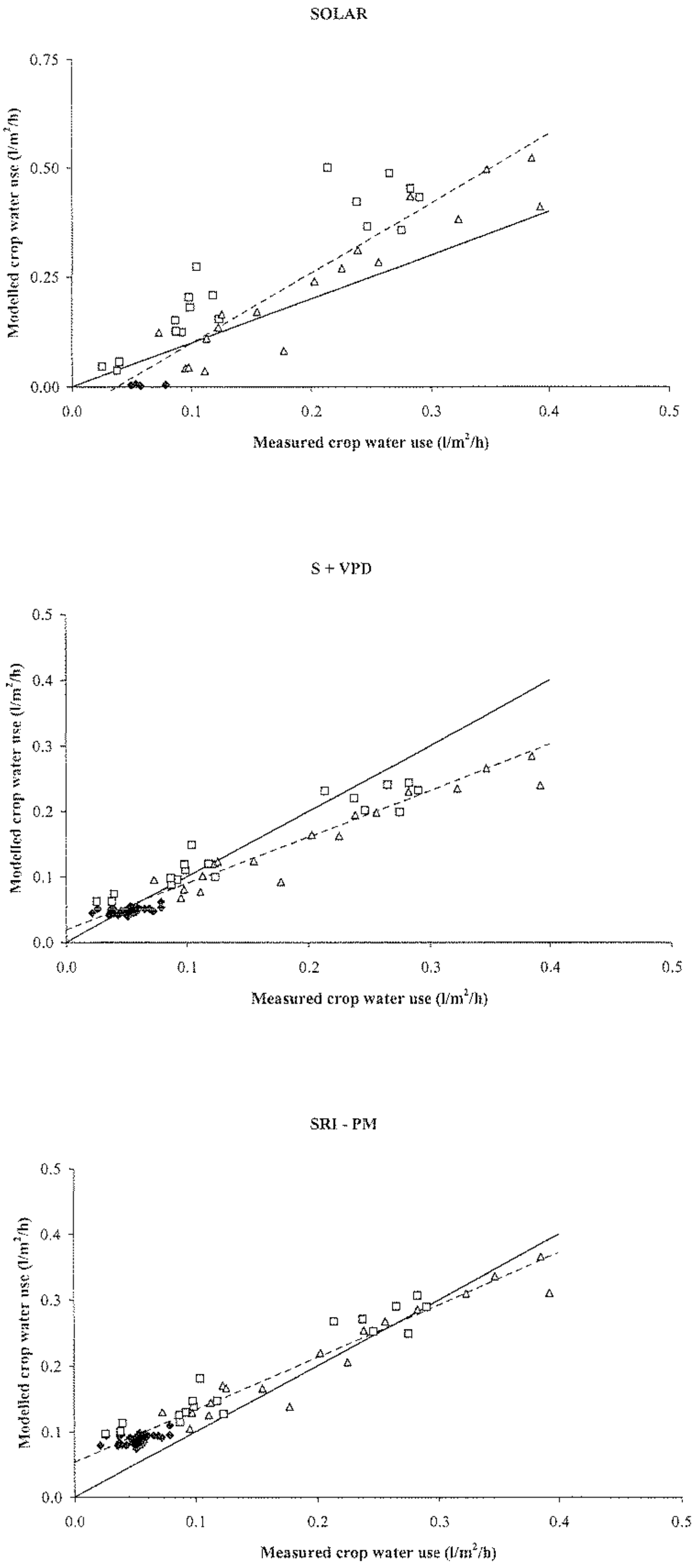
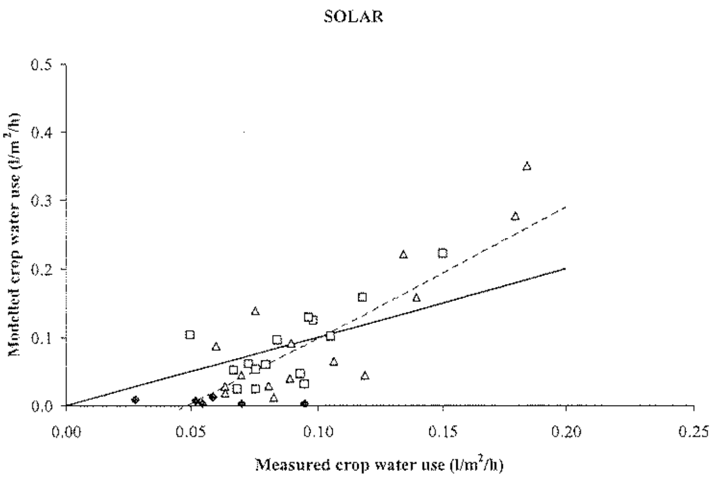
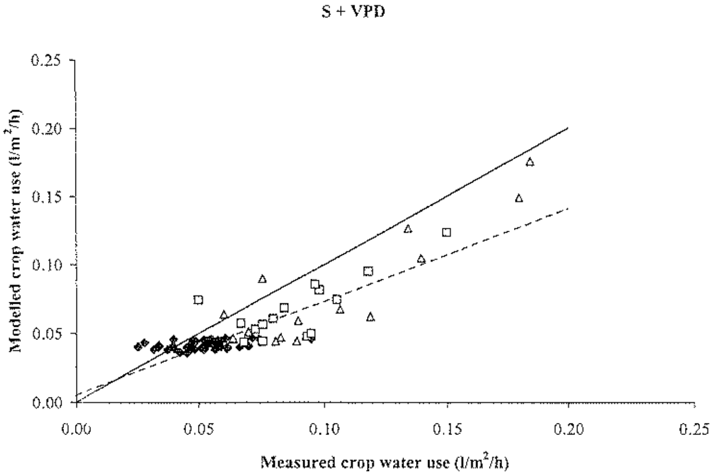


Figure 6. Period 2: Comparison of modelled and measured crop water use. = night, = morning, = afternoon, —— = 1:1 line; - - - - = fitted line


SOLAR


S + VPD

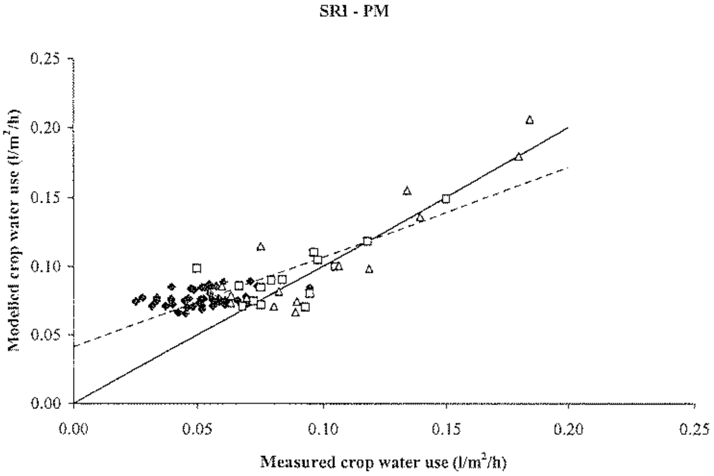

SRI - PM

Figure 7. Period 3: Comparison of modelled and measured crop water use. = night, = morning, = afternoon, —— = 1:1 line; - - - - = fitted line

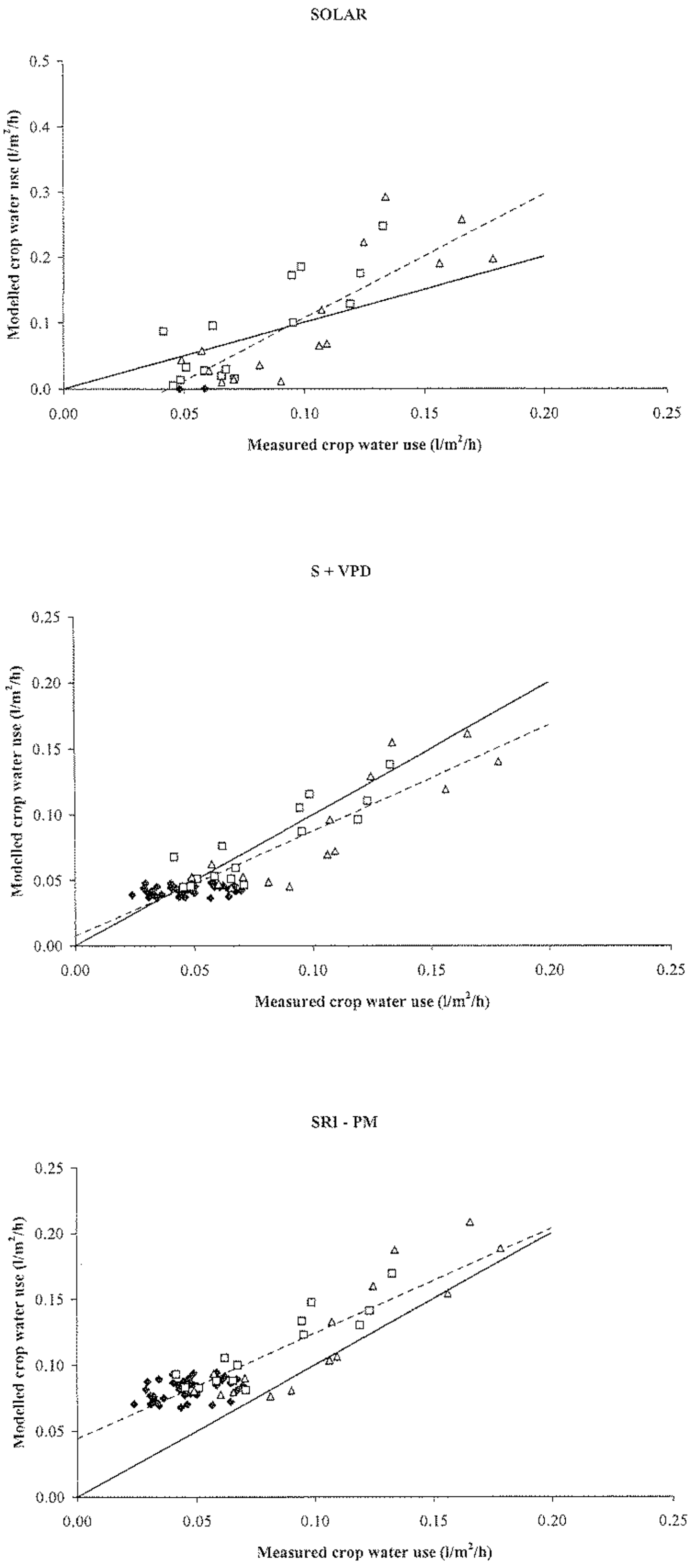


Figure 8. Period 4: Comparison of modelled and measured crop water use. = night, = morning, = afternoon, —— = 1:1 line; - - - - = fitted line

Table 2. Regression coefficients a_o and a_1 assuming a relation $y = a_o + a_1x$ or $y = a_1x$ where x are the measured values of crop water use (WU, l/m^2/h) and y are the modelled values. R^2 (%) is the variance accounted for

Model	Values	Period			
		1	2	3	4
SOLAR	a_0	-0.091	-0.062	-0.093	-0.083
	a_1	1.741	1.603	1.911	1.894
	R^2	93.9	86.8	75.1	74.9
	a_1	1.352	1.287	0.810	0.887
	R^2	85.8	81.1	44.9	48.0
S + VPD	a_0	-0.003	0.018	0.005	0.007
	a_1	0.720	0.712	0.720	0.804
	R^2	93.7	92.6	76.0	79.8
	a_1	0.706	0.806	0.772	0.884
	R^2	93.6	89.9	75.5	78.8
SRI – PM	a_0	0.016	0.053	0.041	0.044
	a_1	0.823	0.798	0.653	0.798
	R^2	91.0	94.9	70.3	80.0
	a_1	0.889	1.068	1.137	1.330
	R^2	90.0	76.5	23.3	34.8

Period 1

The 19 and 21 August were sunny days when the radiation was high whereas the 20 August was mainly overcast. The light transmission averaged over this period was 62%. The global radiation was over four times greater on the first day than on the second yet the crop water use was only twice as much. When radiation levels were high the SOLAR model considerably overestimated the crop water use. Whereas at night when the global radiation is zero the crop water use was typically 0.057 l/m^2/h. Throughout this period the S + VPD model underestimated the crop water use by about 30% whereas the SRI - PM model more accurately predicted crop water use but still underestimated by 10%. These underestimates were consistent for both the morning and afternoon periods. At night the S+VPD model considerably underestimated water use by predicting an average of 0.035 l/m^2/h whereas the SRI - PM model average of 0.064 l/m^2/h was a more accurate prediction.

Period 2

Although the daily totals of radiation were similar for the three days the periods of bright sun varied from day-to-day. Averaged over the three days the light transmission was 57% but on the 12 September the light transmission was low at 52%. The reason for this is not clear but may be due to shadows cast on the solarimeters during periods when the radiation was high. This observation serves to reaffirm the need for models to be based on outside light levels. The SOLAR model overestimated crop water use during all three periods of daylight. In the mornings the SOLAR model considerably overestimated water use whereas in the afternoon the model still overestimated crop water use but the overestimate was smaller. The S + VPD model consistently underestimated crop water use by about 20% during periods of high radiation but accurately predicted the water use at other times. In contrast, the SRI - PM model was accurate at times of high radiation but at other times overestimated crop water use. There were only slight differences in the estimations between the mornings and the afternoons. At night the average water use was 0.051 $l/m^2/h$ which was accurately predicted by the S+VPD model with an average of 0.048 $l/m^2/h$ whereas the SRI - PM model considerably overestimated water use at an average of 0.089 $l/m^2/h$.

Period 3

The 30 September was dull all day, the 1 October was bright in the afternoon and on the 2 October there were a few bright periods. Light transmission averaged over the three days was 67%. The crop water use was 1.44 $l/m^2/d$ on the dull day when the global radiation was 1.5 $MJ/m^2/d$. On the next day when the global radiation was 5.5 $MJ/m^2/d$ the crop water use was only slightly higher at 1.87 $l/m^2/d$. On the dull day the SOLAR model underestimated crop water use throughout the day (and night) and overestimated water use when the sun shone brightly. The S + VPD model slightly underestimated water use during periods of bright sun but for the remaining times the model was a good predictor. This was in contrast to the SRI - PM model which predicted crop water use well during daylight hours but overestimated at night. The average measured water use at night was 0.052 $l/m^2/h$ compared with the S+VPD model prediction of 0.047 $l/m^2/h$ and the SRI - PM prediction of 0.077 $l/m^2/h$

Period 4

There were sunny periods on the 23 and 25 October and the day in between was dull. The average light transmission was 55%. On the dull day the crop used 1.2 l/m^2 of water and on the other days 1.7 to 1.8 l/m^2. The SOLAR model underestimated crop water use during the night and during dull periods and overestimated during bright periods. The S + VPD model accurately estimated crop water use at night (0.043 $l/m^2/h$ compared to a measurement of 0.047 $l/m^2/h$) and during the mornings but underestimated water use during the afternoons. The SRI - PM model tended to overestimate crop water use throughout the period with the largest overestimate occurring at night (0.082 $l/m^2/h$).

Analysis

The coefficient a_1 in Table 2 represents the slope of the regression line and a_0 the intercept when modelled and measured values of crop water use are compared. The analysis can be carried out with the regression line constrained through the origin ($y = a_1x$) in Table 2. A 'good' model would be one in which the coefficient a_1 is near to a value of 1 throughout the season and with a high value for the percent variance accounted for (R^2, %).

The S + VPD model intercept is quite close to zero throughout the experimental period indicating that it is an accurate model during periods when crop water use is relatively low, namely at night and at times of low light levels. However, the model underestimated water use by around 30% in August and this underestimation is reduced to around 15% in October.

The SRI –PM model intercept had positive values, indicating that the model over estimated crop water use at night, but that the model accurately predicted the water use during daylight hours (Figures 5 to 8). Because of the discrepancy between the model and the actual measurement at night, the variance accounted for was reduced as night length increased when the regression line is constrained through the origin.

The SOLAR model is particularly interesting. For all four periods the intercept and slopes were similar, indicating a constant relation between the modelled and measured crop water use. An equation can be developed to describe crop water use based on light integral. The SOLAR model equation can be expressed as 408 ml/m^2 per 100 $J/100cm^2$ of incident radiation measured inside the greenhouse (assume $\lambda = 2450$ J/g). Using the average values of coefficients in Table 2 of a_0 (-0.082) and a_1 (1.787) and a light transmission of 0.65 (for a typical modern glasshouse) it can be shown that a simple crop water use equation can be written as 148 ml/m^2 per 100 J/cm^2 plus 46 $ml/m^2/h$. This suggests that irrigation scheduling should include timed starts **in addition to** applications based on light integral. This compares to current practice of either timed starts **or** irrigation when the light integral reaches a predetermined level.

CONCLUSIONS

1. The SOLAR model considerably overestimated crop water use during periods of high radiation. The overestimate was greater in the mornings than the afternoons. During dull periods the SOLAR model would not supply sufficient water for irrigation and at night no water would be applied even though there is a substantial requirement.

2. The S + VPD model underestimated water use by about 30% under moderate light levels but this reduced to about 10% under low light conditions later in the season. These underestimates were consistent for both the morning and afternoon periods. The S + VPD model was the most accurate prediction of water requirements at night particularly from September onwards.

3. The SRI - PM model was the most accurate of the three models in predicting crop water use during day light hours. However, underestimation of water use occurred during the first period and an overestimation during the last period. At night, there was a slight overestimation of water use in period 1 and this overestimation increased with time so that by the last period the estimation of water was nearly twice that required by the crop.

4. At night crop water use averaged 0.057 $l/m^2/h$ during period 1 and reduced with time so that by the end of the experiment the crop water use averaged 0.047 $l/m^2/h$. These values compare with crop water use at night in the middle of the summer of about 0.07 $l/m^2/h$. These differences are probably due to the water requirements for crop growth rather than transpiration.

5. A simple crop water use model based on light integral and timed starts is presented for the period under investigation (August to October). In modern glasshouses, the crop water requirement equates to irrigation applications of 150 ml/m^2 per light integral of 100 J/cm^2 plus an additional 50 $ml/m^2/h$. (Note that the values have been rounded upwards)

SCIENCE SECTION PC 151

INTRODUCTION

In a review on the current irrigation practices of 25 tomato growers Fussel, *et al.* (1997) found that there appeared to be fundamental differences in water use between tomato crops grown in NFT and substrate run-to-waste systems.

From grower records the average water use for the entire season in NFT was 779 l/m^2 compared to 1381 l/m^2 in rockwool. To account for the potential effects of variations in light receipt by the individual growers Fussel *et al.*, (1997) calculated water use per unit light for the individual growers. Average water use for NFT crops was 215 ml MJ/m^2. Average application to rockwool crops was 353 ml MJ/m^2. They also found that grower records of drainage volume in run-to-waste systems were 300 to 400 l/m^2 per year. When deducted from total application it suggested that uptake was around 1000 l/m^2.

Fussel *et al.*, (1997) concluded that either measurements of drainage from rockwool crops were either consistently inaccurate or that there were fundamental differences in uptake between NFT and rockwool run-to-waste systems.

However the findings of the irrigation review (Fussel *et al.*, 1997) contradict those of Hamer (1998) who found that on experimental crops grown at Silsoe Research Institute NFT crops used more water than those grown in rockwool.

The main objectives of the project were:

- To identify any differences in water use for tomato crops grown in NFT and rockwool run-to-waste systems;

- To accurately measure and record the water use of a long season tomato crop grown in a re-circulated NFT system and in a run-to-waste rockwool system, but otherwise grown under identical cultural conditions, and therefore to provide detailed data in a suitable format that can be used to validate the irrigation model developed at Silsoe Research Institute (PC 142);

- To identify any differences in crop growth habit and fruit yield.

MATERIALS AND METHODS

Cultural details

Variety:	Espero
Sown:	12 February 1998
Planted:	27 March 1998
Planting Density:	2.78 m^2 (11,250 per acre)
Final head density	3.48 m^2 (14,000 per acre)

The tomato crop, *cv* Espero, was planted in a modern 4.2 m Venlo glasshouse at HRI Stockbridge House. In all respects, crop husbandry followed best commercial practice, including a full pesticide and biological control programme. The rockwool crop was irrigated using a standard practice that delivered 150 ml water per plant for every 100 J/cm^2 light accumulated. During the night period (3-hours before sunset and 1-hour before sunrise) the crop was not irrigated. Two timed irrigation cycles were triggered shortly after sunrise. During the day the maximum rest period between irrigation cycles was 2-hours. Plants were supplied via virgin 2-litre per hour Netafim PCJ pressure compensating emitters positioned in the block. The emitters were checked 3 times each week for blockages and sample jars were used to assess the output of randomly selected emitters on a weekly basis. In order to collect runoff from the rockwool treatment the slabs were wrapped in black / white polythene and placed on rigid metal trays with a drainage channel running down one side. The top of the plastic was clipped over the rockwool slabs in order to prevent evaporation of the runoff solution prior to its measurement. In order to stop the runoff solution collecting in the channels and to aid its return the collection channels were positioned on a 1% slope, as the NFT treatment.

Experimental layout

The experimental layout comprised eight double rows of tomato plants with each double row comprising a single experimental plot. NFT plots alternated with rockwool plots giving four replicates of each system (Appendix I). The experimental area was guarded on each side by unrecorded rows.

For recording purposes the rockwool treatments were split into two replicates, named Rockwool 1 and Rockwool 2. There were no treatment differences between these plots; the split was simply a way of improving the accuracy of the measurement of water use, by increasing the number of recordings made.

In the NFT system, water uptake was measured by recording the water needed to maintain the system at a constant level with an electronic water meter with an accuracy of ±0.5% (Litre Meter Ltd). A second water meter was installed into the system as a backup in case of failure.

Schematic diagrams illustrating the flow control and measurement systems for both NFT and rockwool systems are shown in Appendices IIa, IIb and III.

Records

Data collection began when the crop reached the wire (full canopy). The data from the NFT crop was used to validate the model developed by Silsoe Research Institute, and reported within this document (PC 142). The data from the rockwool crop was used to enable a comparison of water use with that of the NFT crop (PC 151).

Water-use and a range of environmental parameters were automatically recorded for both systems;

- NFT flow input
- Rockwool (1 & 2) flow input
- Rockwool (1 & 2) runoff
- Incoming global solar radiation (W/m^2)
- Relative humidity (%RH)
- Air temperature (°C)

The sensors were scanned frequently and the data logged every ten minutes using either Squirrel or Delta Loggers (Delta-T Devices Ltd, Cambridge):

Delta Logger 'Uptake'

- NFT flow input (l/min)
- Kipp 1 (S_i)
- Kipp 2 (S_i)
- Relative Humidity (%RH)
- Air Temperature (°C)

Delta Logger 'Runoff'

- Rockwool 1 runoff
- Rockwool 2 runoff

Squirrel datalogger

- Rockwool 1 input
- Rockwool 2 input

(See Appendix IIa, IIb and III)

The growth of the tomato plants was assessed on four separate occasions, commencing on 21 August 1998 and then at 14-day intervals. The parameters recorded were:

- Leaf length
- Leaf width
- Stem diameter
- Overall plant vigour score

RESULTS

Water use

Comparative daily water use figures for the NFT grown crop against the rockwool-grown crop are shown in Figure 9. Each point represents water use (l/m^2/day). With the exception of five points, where water use in NFT was shown to be higher, the line fits closely to the 1:1 regression line. The results indicate that water use from NFT and rockwool grown crops was similar and that irrigation models developed on crops grown in NFT can be used for crops grown on rockwool run-to waste systems.

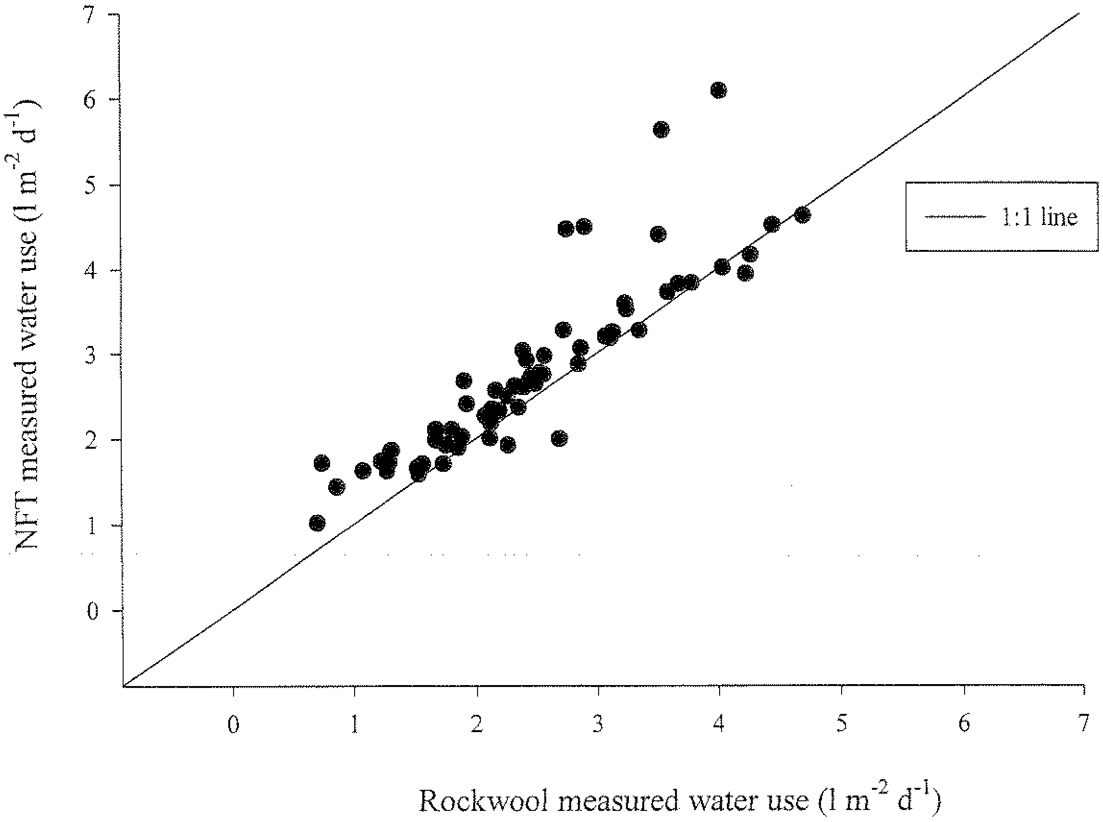


Figure 9. Comparison of water use in the NFT and Rockwool crops for the period Week 31 - Week 40

Crop growth

Apart from slight differences at the second assessment date leaf length and leaf width were similar for plants grown in NFT and rockwool systems (Figures 10a and 10b). Plants grown in rockwool produced thicker stems compared to those grown in NFT. However these differences were small and not statistically significant (Figure 11a).

Assessments of plant vigour score (0-5 where 5 = best) were conducted on four separate occasions during the season. Rockwool grown plants were more vigorous throughout the season compared to those grown in NFT (Figure 11b). However, these differences were only found to be significant at the earlier assessment dates. The highest vigour scores were observed at the second assessment date, which is the same time as when the largest differences in leaf length and leaf width were observed.

Fruit yield

The third truss was removed from the NFT grown plants during week 23. This was necessary in order to redress the generative : vegetative balance of the plants due to the late sowing date and weather conditions. Therefore while the yield data is presented for both the NFT and Rockwool grown crops from May until September, effective comparisons should only be made from August onwards. There was no significant difference in fruit quality (Tables 4 and 5) with 89.6% and 89.2% Class I fruit produced in the NFT and rockwool systems respectively (Table 4). There was also no significant difference in the size grade of Class I fruit produced until the latter part of the season when the NFT grown crop produced significantly more small fruit (47-52 mm) and less large fruit (57-67 mm) (Table 6).

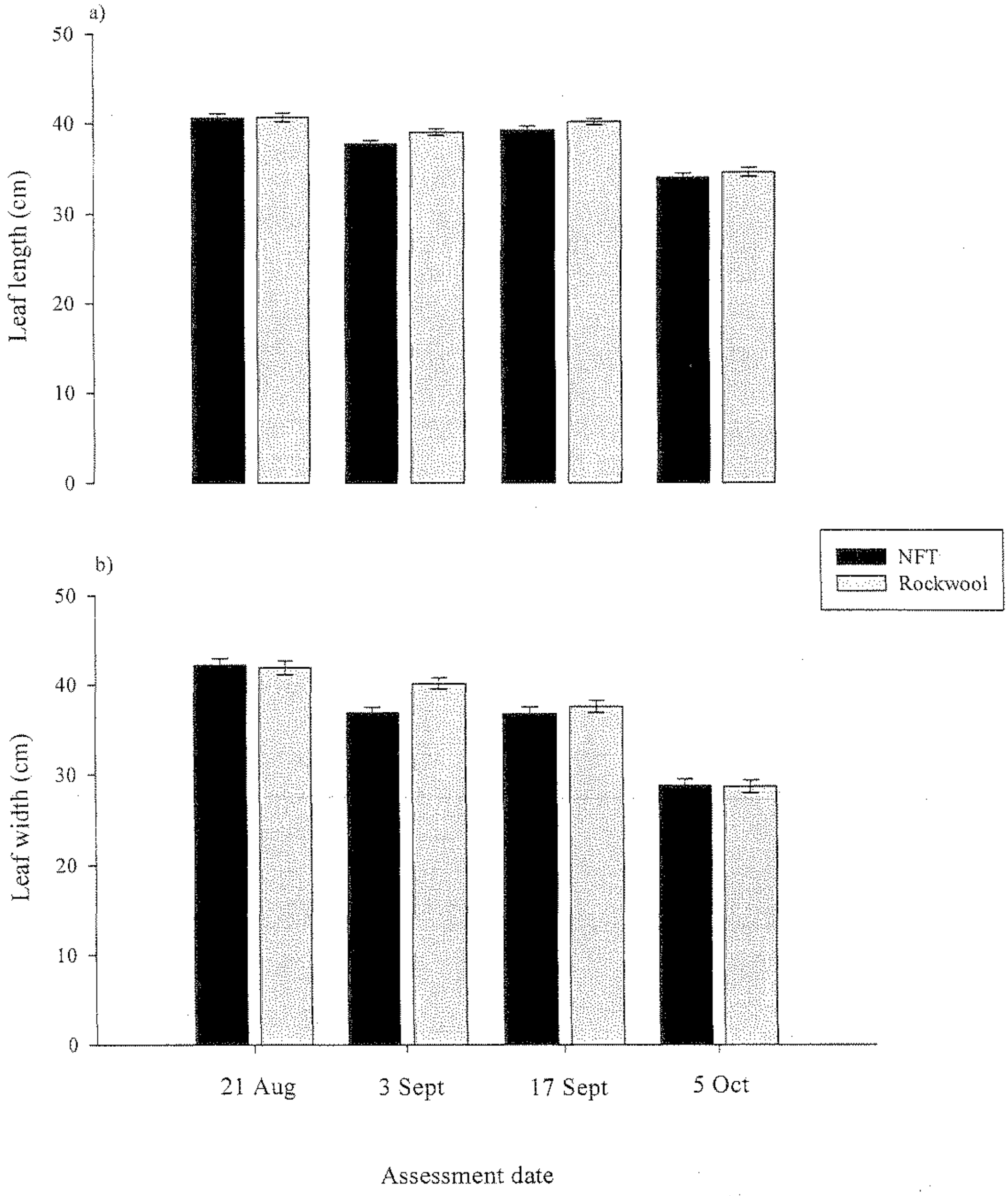


Figure 10. a) Mean leaf length and b) mean leaf width of tomato cv Espero grown in NFT channels or Rockwool substrate
Bars represent standard error of the mean (94 df)

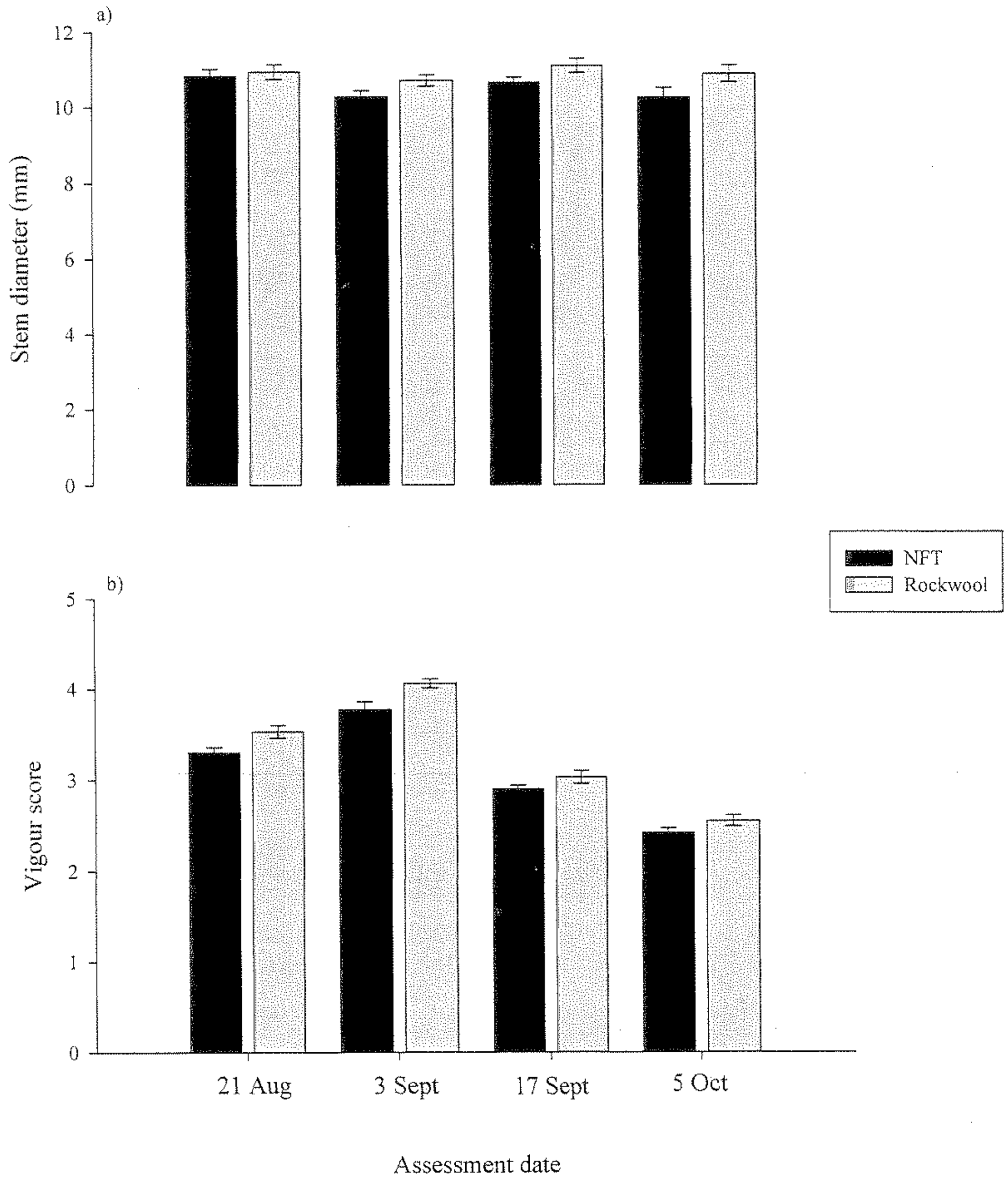


Figure 11. a) Mean stem diameter and b) mean plant vigour score of tomato cv Espero grown in NFT channels or Rockwool substrate
Bars represent standard error of the mean (94 df)

Table 3. Total marketable fruit yield (kg/m^2) of a long-season tomato crop *cv* Espero grown in standard NFT and rockwool systems.

	May/June	July	August	September	October	Total
NFT	9.12	7.30	6.75	7.26	5.14	35.57
Rockwool	11.82	8.36	7.84	7.24	5.86	41.12
SED (6 df)	0.25	0.29	0.19	0.22	0.12	0.58
LSD (P=0.05)	0.63	0.71	0.47	0.54	0.28	1.42
Significance	***	*	***	NS	***	***

Please note that effective yield comparisons should only be noted from August onwards due to the differences in the growth habit and vigour of the NFT crop in the period up to June.

Table 4. Percentage Class I fruit of total yield of a long-season tomato crop *cv* Espero grown in standard NFT and rockwool systems.

	May/June	July	August	September	October	Total
NFT	83.98	89.91	90.05	93.48	93.43	89.65
Rockwool	85.82	90.70	87.73	93.24	91.42	89.28
SED (6 df)	1.06	0.88	1.24	0.61	0.47	0.50
LSD (P=0.05)	2.59	2.15	3.03	1.49	1.15	1.22
Significance	NS	NS	NS	NS	**	NS

Table 5. Percentage Class II fruit of total yield of a long-season tomato crop *cv* Espero grown in standard NFT and rockwool systems.

	May/June	July	August	September	October	Total
NFT	12.62	9.00	9.02	5.62	6.23	8.84
Rockwool	11.14	7.74	10.96	5.77	8.19	9.04
SED (6 df)	1.06	0.78	1.13	0.53	0.44	0.47
LSD (P=0.05)	2.59	1.90	2.76	1.30	1.09	1.15
Significance	NS	NS	NS	NS	**	NS

Table 6. Fruit size distribution (Percentage of Class I yield) of a long-season tomato crop *cv* Espero grown in standard NFT and rockwool systems.

	May/June	July	August	September	October	Total
Size 47–52 mm						
NFT	1.37	6.97	11.73	16.49	32.51	12.4
Rockwool	1.53	8.63	12.38	15.44	24.77	10.98
SED (6 df)	0.25	0.76	0.94	1.35	0.73	0.44
LSD (P=0.05)	0.61	1.85	2.30	3.30	1.79	1.09
Significance	NS	NS	NS	NS	**	*
Size 52-57 mm						
NFT	4.00	25.50	26.57	26.64	26.34	20.91
Rockwool	4.87	25.78	26.80	25.86	26.78	20.37
SED (6 df)	0.74	1.58	0.95	0.60	1.14	0.48
LSD (P=0.05)	1.80	3.85	2.32	1.47	2.78	1.16
Significance	NS	NS	NS	NS	NS	NS
Size 57-67 mm						
NFT	94.53	66.00	60.52	54.29	32.73	64.32
Rockwool	93.52	63.9	59.25	56.28	42.03	66.61
SED (6 df)	0.84	2.28	1.58	1.62	1.85	0.69
LSD (P=0.05)	2.07	5.58	3.87	3.97	4.52	1.70
Significance	NS	NS	NS	NS	**	*

CONCLUSIONS

1. The results indicate that NFT grown crops use a similar amount of water to those grown in rockwool. These findings are in agreement with those of Hamer (1999) in press.

2. Irrigation models developed on crops grown in NFT can be used for crops grown on rockwool run-to waste systems

3. The large discrepancies observed from growers figures on water use in NFT and Rockwool grown tomato crops reported in PC 119, is probably attributed to inaccurate measurement of drainage volumes as suggested by Fussel *et al.* (1997).

4. Significant differences occurred in the vigour and the yield of the NFT and Rockwool grown crops up until August which was in part due to crop management practices. Therefore it is not possible to accurately evaluate the efficiency of water use versus yield in these test crops over long periods of time.

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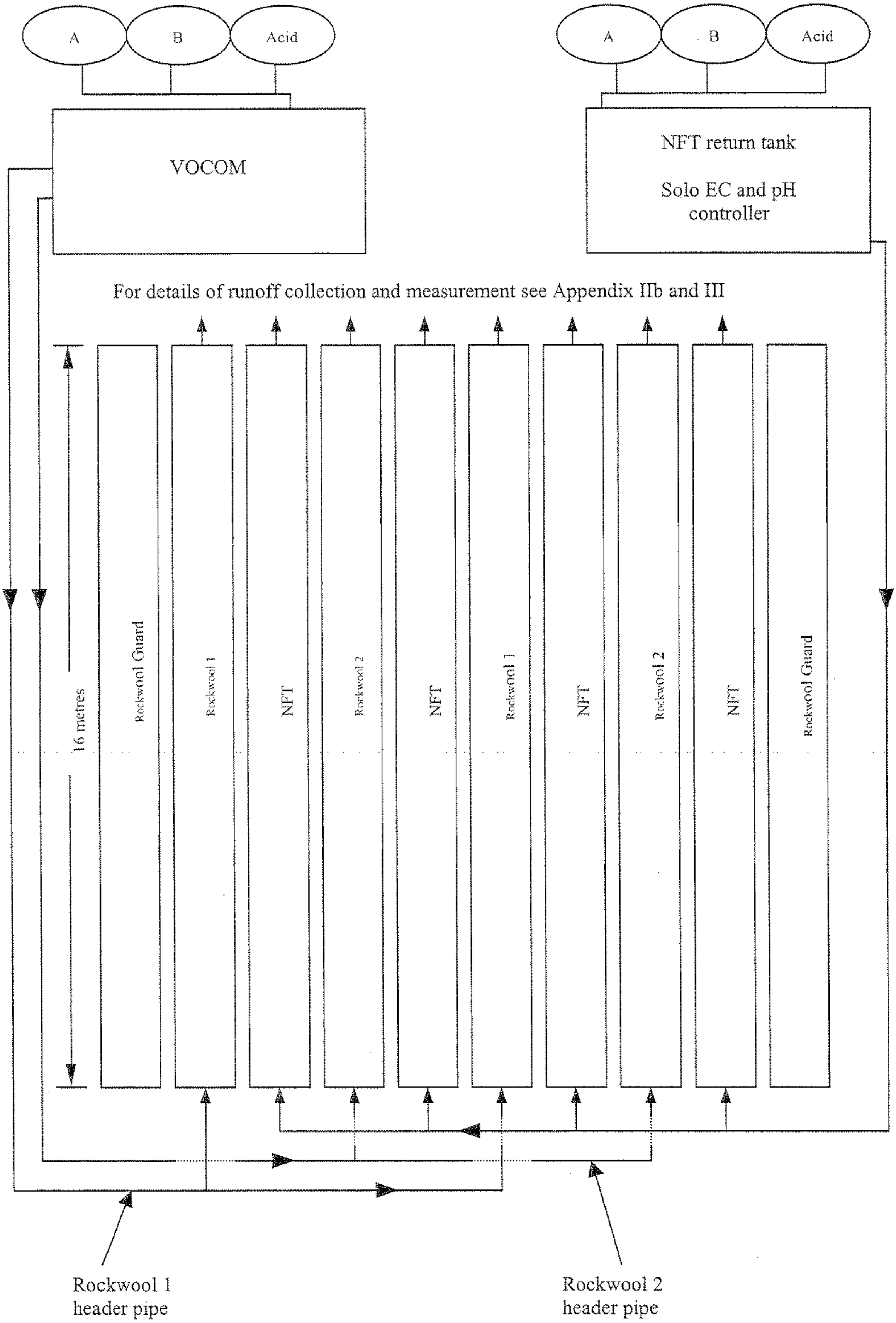
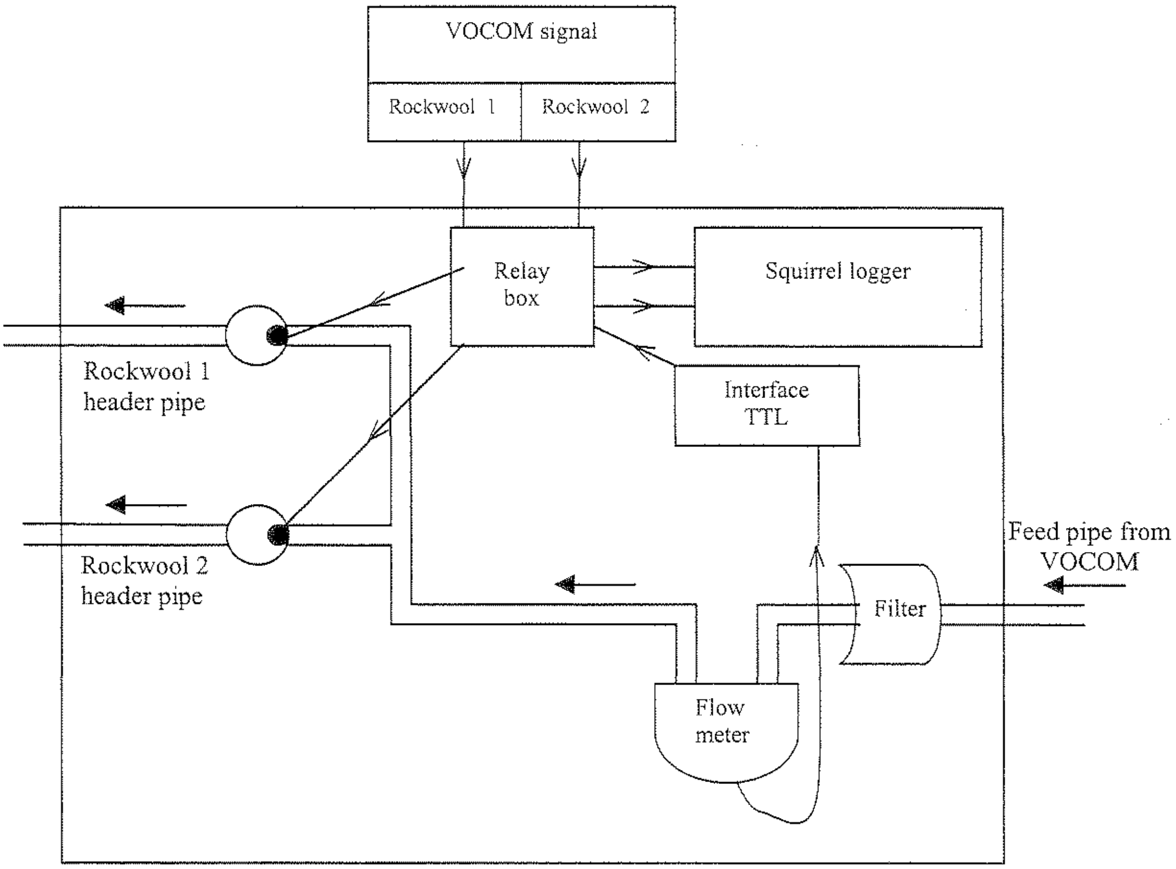
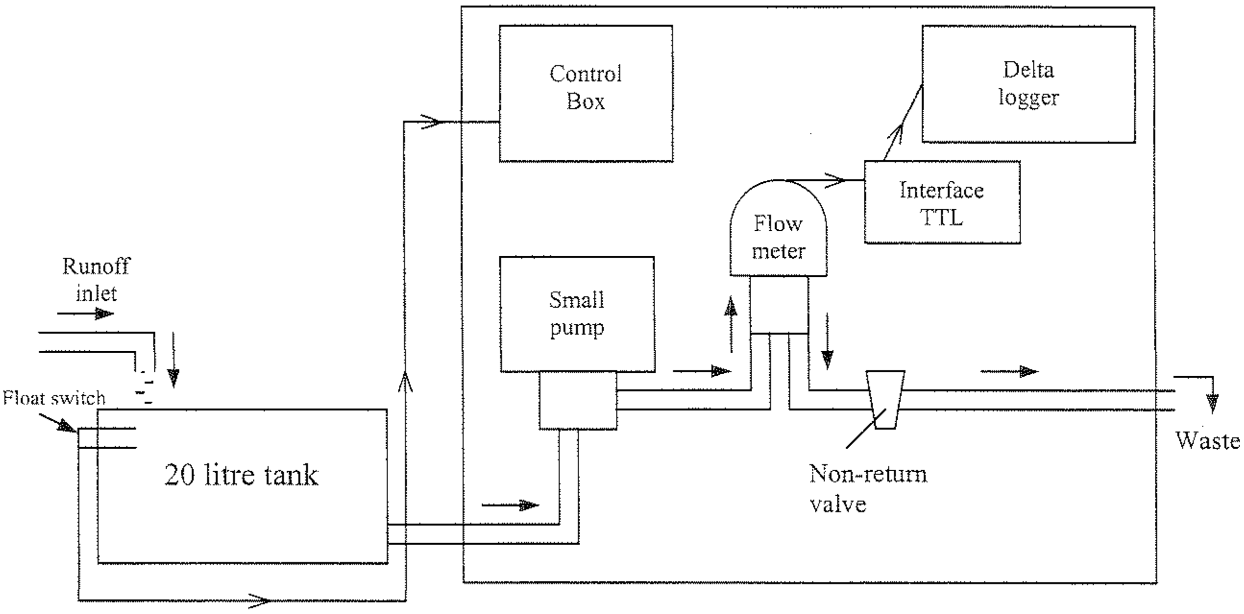
Appendix I. Experimental layout and plan of irrigation and feed units



Appendix IIa. Schematic diagram of rockwool flow control and measurement System



Appendix IIb. Schematic diagram of rockwool runoff measurement system



Appendix III. Schematic diagram of NFT flow control and measurement system