Improvements in Automatic Irrigation of Peat-grown Greenhouse Tomatoes

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Additional index words. electronic tensiometers, potential evapotranspiration (PET), electrical conductivity

Summary. An automatic irrigation system was designed for use on greenhouse tomatoes growing in peat-based substrates. This system uses electronic tensiometers to monitor continuously substrate matric potential (SMP) in peat-bags. The system also uses the Penman equation to evaluate potential evapotranspiration (PET) through the acquisition of many greenhouse environmental parameters. Through a series of linear equations, estimates of PET are used in a computer-controller system to vary the electrical conductivity (EC) of irrigated nutrient solutions, as well as SMP setpoints at which irrigations are started. Such modifications to current irrigation management systems may improve fruit quality and reduce the risk of water stress during periods of high PET by irrigating more frequently with less-concentrated nutrient solutions. Conversely, during periods of low PET, irrigation is less frequent with more-concentrated nutrient solutions. Although no differences were found in fruit number or overall yield using variable nutrient solution EC, plant fresh weight was higher in those treatments. It is concluded that an integrated tensiometer–PET system may give increased precision to irrigation management and the control of crop growth in the greenhouse.

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Environmental effects on plant water requirements can be estimated using the Penman equation for potential evapotranspiration (PET; Campbell, 1986; Monteith, 1973; Penman, 1948). PET estimates have been shown to give a reliable indication of water use in greenhouse tomatoes growing in peat-based media (Norrie et al., 1994). Aikman and Houter (1990) indicated that fruit quality and yield may be improved by correcting for imbalances between plant growth and mineral nutrition due to differing environmental conditions—most notably light and humidity—the two principal components of the Penman equation. Included in several suggestions to better coordinate growth with environmental conditions, they suggest increasing the salinity of irrigated solutions during low light (or low potential evapotranspiration) to increase xylem nutrient concentration. This may result in increased calcium supply to the upper canopy, thereby reducing the risk of some nutritional disorders (e.g., blossom-end rot; Ehret and Ho, 1986). In an integrated irrigation system, PET estimates can be used as an indicator of potential transpiration and evaporation to predict more accurately plant needs for water and nutrients.

However, accurate PET estimates require the measurement of many atmospheric parameters, such as net radiation, humidity, and temperature, along with estimates of the resistance to heat and vapor transfer according to leaf dimensions (Campbell, 1986). Although more-empirical formulas can be used to evaluate PET (Verma et al., 1983), direct measurements of individual environmental parameters give the most accurate estimates.

PET estimates can indicate water and nutrient requirements, whereas irrigation timing for peat-bag-grown greenhouse tomatoes can be improved by the use of electronic tensiometers. Electronic tensiometers have proven to be very successful at improving irrigation frequency relative to crop water needs (Burger and Paul, 1987; Gobeil et al., 1989; Lieth and Burger, 1989; Norrie et al., 1994). While continuously monitoring substrate matric potential (SMP) with electronic tensiometers, computers can be programmed to begin or end irrigations at specific SMP setpoints. Various SMP setpoints have been examined on organic and peat-based substrates. Most studies suggest a starting SMP irrigation setpoint somewhere between –6.0 and –10.0 kPa, depending on substrate composition (De Boodt and Verdonck, 1972; Duval, 1992; Frenz and Lechl, 1981; Goodman, 1983). A starting irrigation setpoint between –4.0 and –5.0 kPa gives the best management for tomatoes grown in 24-liter bags (Gobeil et al., 1989; Norrie et al., 1994), with irrigation continuing until bags are nearly saturated (greater than –1.0 kPa SMP). However, irrigation may be started earlier during periods of high PET, or later at lower SMP during times of low PET. However, no irrigation management system now available can modify both irrigation SMP setpoints and nutrient solution concentration according to greenhouse environmental conditions.

The objective of this experiment was to develop an integrated tensiometer–PET system that modifies nutrient solution concentration and SMP irrigation setpoints in response to changes in greenhouse environment. Preliminary testing of the system is performed on a tomato crop. Component variables used in the Penman equation also were analyzed in a sensitivity analysis to examine the influence of specific environmental parameters on PET estimates.

Materials and methods

'Caruso' tomato plants were grown in a glass greenhouse at the Horticultural Research Center at Laval Univ., near Quebec City, Que., beginning Aug. 1992. Three-week-old seedlings were transplanted into 24-liter peat-bags (Allegro Peat-Bags, Premier Peat Moss; 70% peat : 30% perlite) on 10 Sept. at a planting density of 3.2 plants / m^2 (three plants per bag). A randomized complete-block design incorporated four treatments replicated in twelve blocks. Each block consisted of four peat-bags containing three plants each. High-pressure sodium lighting was used to give an additional 12 $W \cdot m^{-2}$ to natural light. Plants were pollinated three times per week using an electric wand. Plants were irrigated with a complete nutrient solution (from A and B stock solutions) according to specific treatments. The flow rate from drip emitters was ≈10 $ml \cdot min^{-1}$.

In addition to fresh and dry plant weight, and yield and fruit weight, irrigation data (volume irrigated / day, total drainage/day) was collected daily (if present) during the 8-week period of fruit development. Data were examined for normality and homogeneity? and analyzed by analysis of variance (ANOVA). In cases of a significant F-value, mean separations by least significant difference (LSD) test were performed (Gomez and Gomez, 1984).

Integrated irrigation system. The integrated tensiometer-PET system examined the following four irrigation regimes: 1) fixed EC (2.5 $dS\cdot m^{-1}$) and tension setpoint (–5.0 kPa); 2) variable EC (between 1 and 4 $dS\cdot m^{-1}$) and fixed-tension setpoint (5.0 kPa); 3) variable-tension setpoint (between -3.0 and -7.0 kPa) and fixed EC (2.5 $dS\cdot m^{-1}$); and 4) variable EC (1 to 4 $dS\cdot m^{-1}$) and tension setpoint (-3.0 to –7.0 kPa). All variable irrigation controls reflected changes in PET as calculated from greenhouse environmental data. SMP measurements were made with electronic tensiometers connected to a central computer, which controlled the start of irrigation (Fig. 1). Irrigation began only when two of four tensiometers, within anyone treatment, had reached the starting setpoint. Irrigation was stopped when three of four tensiometers indicated SMP was more positive than –1.0 kPa (close to saturation; Fig. 2). Net radiation, humidity, and temperature, along with estimates of the resistance to heat and vapor transfer according to leaf dimensions (Campbell, 1986), were measured or calculated and used in the Penman equation for PET (see Norrie et al., 1994).

The Penman equation can be written as,

$$\lambda E_p = (s\cdot R_n + \{[\rho c_p(e_{sa} - e_a)] \times (r_h)^{-1}]) [s + \gamma]^{-1}$$

using the following variables: λE_p, potential evapotranspiration ($W\cdot m^{-2}$; unit becomes $J\cdot m^{-2}$ if integrated over time; λ is the latent heat of vaporization of water); s, slope of saturation vapor density curve (at air temperature; kPa/°C); R_n, net amount of global radiation received at leaf surface ($W\cdot m^{-2}$); ρc_p, volumetric heat capacity of air (1200 $J\cdot m^{-3}\cdot C^{-1}$ at 20 C); e_{sa}, saturation vapor pressure (at air temperature; kPa); e_a, current vapor pressure (at air temperature; kPa); and γ is the thermodynamic psychrometric constant (0.066 kPa/°C). The resistance to heat transfer (r_h), used in the Penman equation, was estimated from the following equation: $r_h = 307(d/u)^{1/2}$, where d (leaf surface diameter) is expressed in meters and u (windspeed) in $m\cdot s^{-1}$ (Campbell, 1986). With this equation, leaf surfaces are assumed to be wet; therefore, resistances to heat and vapor (r,) transfer are equal. Although it is difficult to measure the diameter of a tomato leaf (considering its asymmetry), if d = 0.20 m and u = 1.5 $m\cdot s^{-1}$, then r_h equals 112 $s\cdot m^{-1}$. For our PET calculations, we have assumed a standard r_h of 100 $s\cdot m^{-1}$.

Calculated values and tensiometer readings were recorded every minute, with averages calculated every 20 min. In order to have reference values for use in irrigation control algorithms, seasonal averages of environmental parameters also were calculated.

A sensitivity analysis was carried out on parameters of the Penman equation. Each of the principal components was varied by a factor of ±100%, from an arbitrary standard value, while other variables of the Penman equation were held constant.

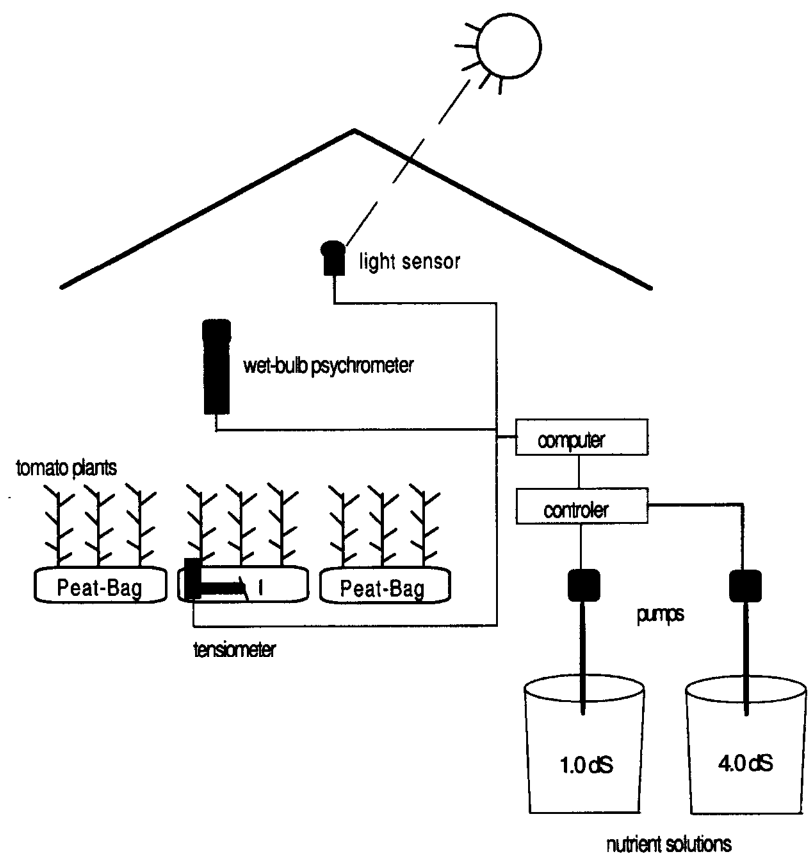

Fig. 1. *Schematic diagram illustrating experimental setup for irrigation of tomatoes in peat-based substrate according to substrate matric potentials (SMP). Environmental effects on irrigation requirements are estimated using the Penman equation for potential evapotranspiration (PET). Irrigation management is improved by varying nutrient solution concentration and SMP setpoints to reflect estimates of plant requirements for water and nutrients based on PET calculations.*

Results and discussion

Before discussing the application of the integrated irrigation system to a tomato crop, it is important to describe how the system control algorithms are defined and calculated.

PET-controlled EC. A computer irrigation program was written using a simple linear equation to calculate the concentration of nutrient solution to be applied to plants at any particular PET estimate. Plants were irrigated from two stock basins containing solutions of 1.0 and 4.0 $dS\cdot m^{-1}$. The formula used to control irrigation is written as follows:

EC to be applied = (EC programmed) + X [(actual PET) – (average seasonal PET)]

In order to determine the "EC to be applied," within the 1–4 $dS\cdot m^{-1}$

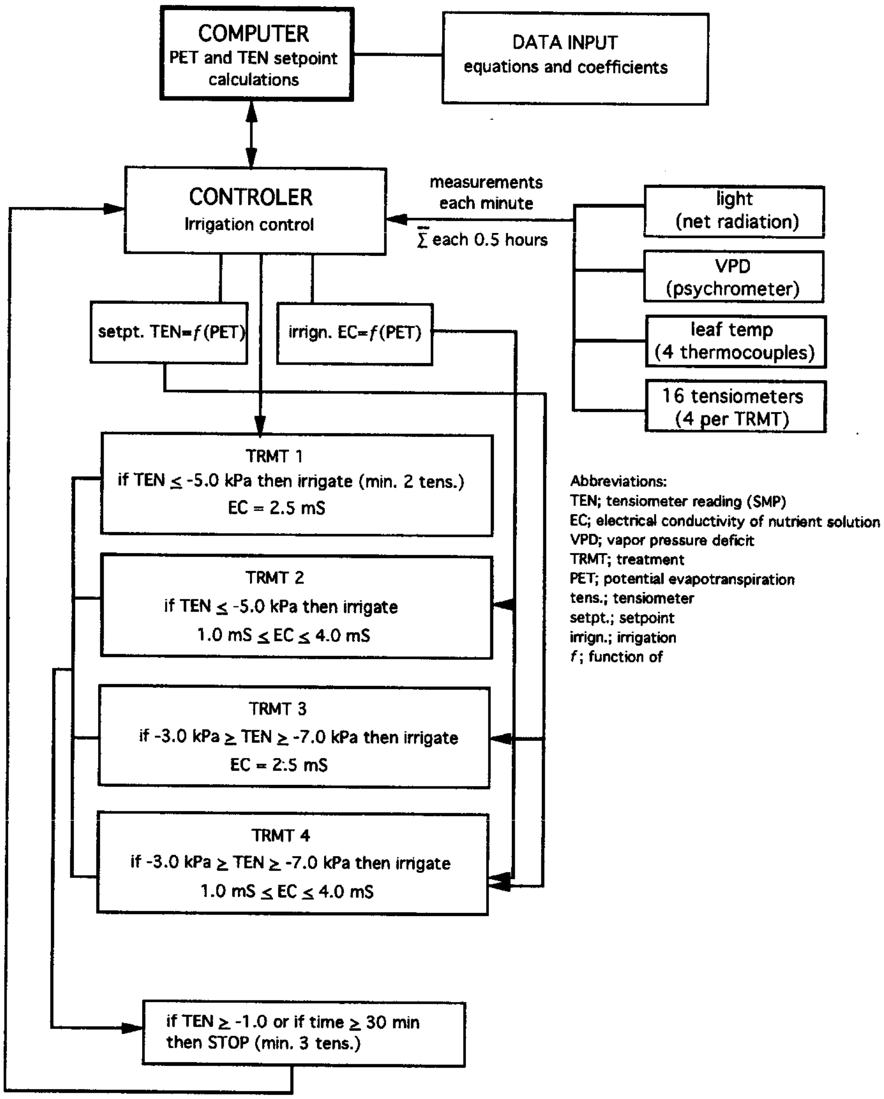

Fig. 2. *Flow chart outlining computer information acquisition, data processing and decision making, and fertigation control for the four treatments used in the preliminary study.*

limits, it is first necessary to calculate an X coefficient based on these limits. To do this, selected values for all variables except the coefficient are used in the equation. While the "EC to be applied" changes according to the "actual PET," maximum values for these two variables were inserted temporarily into the formula to calculate the X coefficient. Once X is calculated, it becomes a constant in the equation along with "EC programmed" and "average seasonal PET" variables, while "actual PET" values vary with environmental conditions and, in turn, influence the "EC to be applied" value. For example, a more-dilute solution is desired at higher PET; therefore, the following would be true:

$$1\ \mathrm{dS{\cdot}m^{-1}} = 2.5\ \mathrm{dS{\cdot}m^{-1}} + X\ (700\ \mathrm{W{\cdot}m^{-2}} - 350\ \mathrm{W{\cdot}m^{-2}})$$

$$X = -0.00428$$

In the example, 2.5 $\mathrm{dS{\cdot}m^{-1}}$ is the average EC desired over the growth of the crop; 700 $\mathrm{W{\cdot}m^{-2}}$ is the average maximum for the season, but it is used here as the "actual PET" to calculate the EC of the weakest solution irrigated (1 $\mathrm{dS{\cdot}m^{-1}}$), 350 $\mathrm{W{\cdot}m^{-2}}$ is the average seasonal PET, and 1 $\mathrm{dS{\cdot}m^{-1}}$ is the minimum EC. Once X is then calculated, any PET estimate above 700 $\mathrm{W{\cdot}m^{-2}}$ results in irrigation of the weakest possible nutrient solution (1.0 $\mathrm{dS{\cdot}m^{-1}}$). Conversely, at a PET of 0 $\mathrm{W{\cdot}m^{-2}}$, the maximum solution concentration of 4.0 $\mathrm{dS{\cdot}m^{-1}}$, representing the other end of EC "window," is the maximum EC that can be irrigated.

Coefficients are calculated so that if PET estimates equal seasonal averages, then a solution EC of 2.5 $\mathrm{dS{\cdot}m^{-1}}$ (halfway between 1.0 and 4.0 $\mathrm{dS{\cdot}m^{-1}}$) is irrigated. The "window" around the 2.5 $\mathrm{dS{\cdot}m^{-1}}$ average can be made smaller or larger simply by varying the value of the coefficient (X must be recalculated), or by changing the stock solution concentrations (irrigated solutions are mixed from two stock EC solutions of 1 and 4 $\mathrm{dS{\cdot}m^{-1}}$ to achieve EC). To show how X is used in the computer algorithm to reset the setpoints, consider the following:

EC to be applied = (EC programmed) + X [(actual PET) – (average seasonal PET)]

$$\text{EC to be applied} = (2.5\ \mathrm{dS{\cdot}m^{-1}}) + -0.00428\ [(462\ \mathrm{W{\cdot}m^{-2}}) - (350\ \mathrm{W{\cdot}m^{-2}})]$$

$$\text{EC to be applied} = 2.02\ \mathrm{dS{\cdot}m^{-1}}$$

In this example, a solution of 2.0 $\mathrm{dS{\cdot}m^{-1}}$ is irrigated if PET= 462 $\mathrm{W{\cdot}m^{-2}}$. If a constant 2.5 $\mathrm{dS{\cdot}m^{-1}}$ is desired, then X =0. Other X coefficients can be calculated easily for changing seasonal PET averages or for changes in maximum/minimum solution concentrations.

PET-controlled irrigation setpoints. Similar formulas can be adapted to control SMP irrigation setpoints. The same seasonal average value for PET is used along with the average SMP setpoint desired for the season. For simplicity, all SMP values were recorded as positive numbers during our experiments. An example of SMP calculations gives the following:

SMP setpoint = (programmed SMP setpoint) + Y [(actual PET) – (average PET)]

or if,

$$3.0\ \mathrm{kPa} = 5.0\ \mathrm{kPa} + Y\ (700\ \mathrm{W{\cdot}m^{-2}} - 350\ \mathrm{W{\cdot}m^{-2}})$$

$$Y = -0.0571$$

As with the EC calculations, the resulting Y coefficient is used in the computer program while the SMP setpoint and actual PET become the unknowns. Using this formula and Y coefficient, if PET estimates rise above the 350 $\mathrm{W{\cdot}m^{-2}}$ seasonal average, irrigations will begin at SMP setpoints more positive than –5 kPa (to a minimum of –3 kPa), and more negative than –5 kPa if PET estimates fall below the seasonal average (to a maximum of –7 kPa). Irrigation automatically ends when substrates are saturated (greater than –1 kPa). Changes in the range or "window" of SMP setpoints are made in the same way as those made for solution EC—through changes in the Y coefficient.

Generally, the relationship between SMP setpoint, nutrient solution concentration, and predicted potential evapotranspiration is linear for two principal reasons: 1) proportional increases in solution concentration are almost linear between 1 and 4 $dS{\cdot}m^{-1}$ when solutions are mixed from two different stock tanks, and 2) the relationship between SMP and integrated PET appears to be linear between –1 and –7 kPa (Norrie et al., 1994).

Time-averaged EC. Salinity buildup in peat substrates can be alleviated simply by over-irrigating with water. Many growers carry out a "leaching" each morning (over-irrigations to ≈ 20% of the amount irrigated), especially during periods of high light or high PET. Along-term average EC was calculated to achieve a more-constant EC over longer periods. This reduces salt accumulation in the substrate if the "EC to be applied" is calculated to be greater than 2.5 $dS{\cdot}m^{-1}$ for a prolonged period. Similarly, EC of the irrigated solution is increased if the long-term average is lower than 2.5 $dS{\cdot}m^{-1}$. Over a fixed number of irrigations the applied solution concentration is decreased or increased by a small percentage during each irrigation until a desired "long-term average" is achieved. An example of a weighted or time-averaged EC calculation is shown below. Three different irrigation periods having different irrigated solution EC are presented as follows:

long-term average EC =

$$(\text{time} \times \text{EC1}) + (\text{time} \times \text{EC2}) + (\text{time} \times \text{EC3}) / \text{total irrigation time}$$

or, long-term average EC =

$$(30\text{min} \times 1.5\ dS{\cdot}m^{-1}) + (15\ \text{min} \times 3.0\ dS{\cdot}m^{-1}) + (25\ \text{min} \times 2.0\ dS{\cdot}m^{-1})/70\text{min}$$

$$= 140\ dS{\cdot}m^{-1}{\cdot}min^{-1}/70\ \text{min}$$

$$= 2.0\ dS{\cdot}m^{-1}$$

The average EC irrigated over the last 70 min of irrigation time is therefore calculated using this equation. Knowing the time-averaged EC, as well as the "EC to be applied," the average EC irrigated over the growing period can be adjusted from the following equation:

$$\text{EC irrigated} = (\text{PET calculated EC}) + Z\ [(\text{average EC desired}) - (\text{long-term average EC})]$$

or, if we use the values calculated above,

$$\text{EC irrigated} = 2.02\ dS{\cdot}m^{-1} + Z\ (2.5\ dS{\cdot}m^{-1} - 2.0\ dS{\cdot}m^{-1})$$

$$\text{EC irrigated} = 2.27\ dS{\cdot}m^{-1}$$

If Z = 0.5, then the "irrigated EC" is calculated to be 2.27 $dS{\cdot}m^{-1}$, even though an EC of 2.02 $dS{\cdot}m^{-1}$ was calculated from the actual PET (if PET= 462 $W{\cdot}m^{-2}$, as in the example before). A marginal increase in EC attempts to meet a long-term average of 2.5 $dS{\cdot}m^{-1}$. A long-term average correction factor also protects against continued irrigation at EC higher or lower than 2.5 $dS{\cdot}m^{-1}$ by accounting for the salinity of solutions already irrigated. However, most irrigations occur during the day when PET is greatest; therefore, the probability of having continuous irrigation of more concentrated solutions (>2.5 $dS{\cdot}m^{-1}$), is very low.

Marginal increases or decreases in solution salinity also can be modified by changes in the coefficients used. The use of time-averaged EC also reduces the frequency of daily "leachings" necessary to control salt buildup. Drainage measurements from once-per-week "leachings" indicate that media salt buildup was, on average, kept well below 4 $dS{\cdot}m^{-1}$ (data not shown). This indicates a lower likelihood of reduced yield or fruit quality due to substrate salt buildup. However, because the risk of some buildup is present, the system has been modified further to over-irrigate plants automatically by ≈ 20% of the volume irrigated, every 10 irrigations, to effectively leach soluble salts.

Irrigation control. Once the salinity and tension setpoints are calculated, plants are irrigated in 10 × 1-min cycles. For example, if a solution of 2.5 $dS{\cdot}m^{-1}$ is called for, the system irrigates for 5 min from each basin. Disproportionate irrigations can be applied (between 1 and 4) to a maximum resolution time of 1 min (for example, 1 min at 1 $dS{\cdot}m^{-1}$:9 min at 4 $dS{\cdot}m^{-1}$ or 2 min : 8 rein, etc.) to

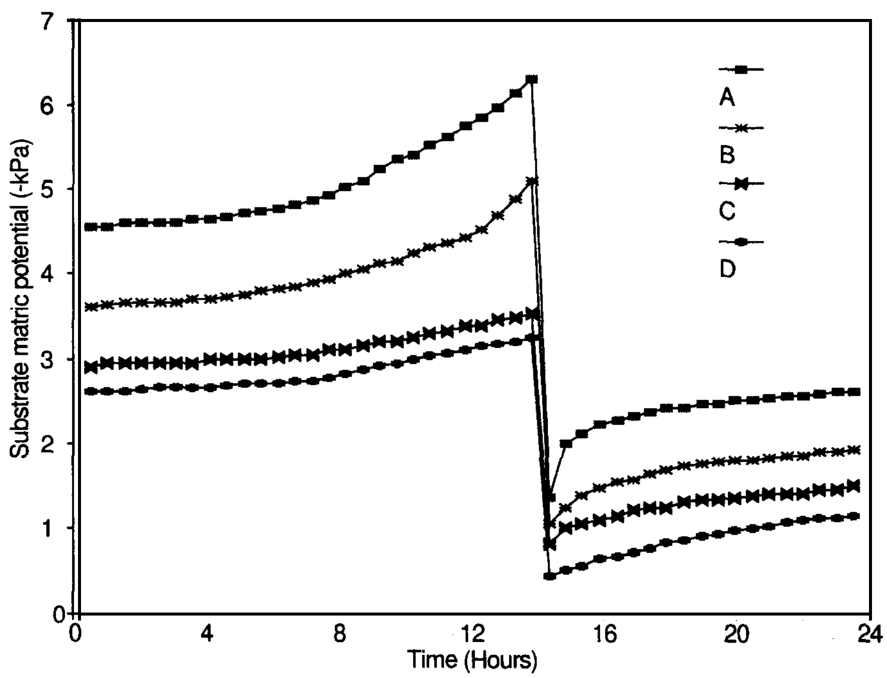

Fig. 3. ***Diurnal profiles of SMP as measured by four electronic tensiometers (A, B, C, and D) for tomato plants growing peat-based substrate on 10 Oct. 1992. Irrigation began at about 14:00, when two of four tensiosmeters indicated SMP below -5.0 kPa. Irrigation was stopped when three tensiometers indicated SMP above -1.0 kPa. Profiles are from plants receiving the same treatment.***

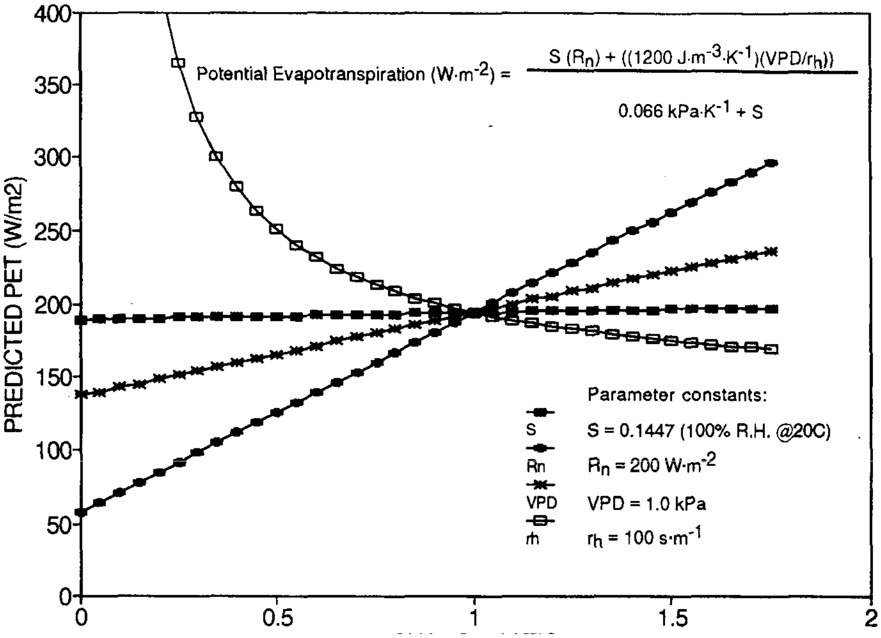

Fig. 4. *Sensitivity analysis of the Penman formula, showing the effect of varying individual environmental parameters, by percentage (change ratio), while holding other parameters at constant values. Abbreviations: S, slope of saturation vapor pressure curve; R_n, net radiation ($W{\cdot}m^{-2}$); VPD, vapor pressure deficit (kPa); r_h, resistance to beat tranfer ($s{\cdot}m^{-1}$). Constants used in the equation are as follows: psychrometric constant (0.066 kPa/°C) and the volumetric beat capacity of air (1200 $J{\cdot}m^{-3}{\cdot}K^{-1}$).*

achieve the desired EC. One minute is required for the computer to accumulate data determining whether or not irrigation should proceed, according to SMP, and at what EC. Irrigations are terminated when substrate water potentials reach the saturation level (–1 kPa). Information from uncompleted irrigation cycles is stored in the computer and the next irrigation is adjusted in accordance with the time-averaged and desired EC originally programmed (2.5 $dS{\cdot}m^{-1}$). Figure 2 illustrates the logic involved in the "decisionmaking" process and indicates the four treatments used in our preliminary study. Figure 3 indicates the process used in starting or stopping irrigation in the fixed "control" treatment, Note that two tensiometers are needed to begin irrigation (at -5.0 kPa) and three are needed to stop irrigation (at –1.0 kPa).

Sensitivity analysis. The Penman equation is generally accepted as being one of the best methods for estimating PET (Campbell, 1986). The importance of the individual environmental parameters in the prediction of PET is seen through a sensitivity analysis of the Penman equation. Figure 4 illustrates the relative contribution of each parameter to overall predicted PET, while other parameters are held constant. A large change in the slope of the saturation vapor pressure-temperature curve does not greatly affect predicted PET. The greatest effects on estimated PET are due to changes in vapor pressure deficit (VPD), calculated from wet- and dry-bulb measurements, and the net radiation (R_n) received by the crop. A large increase in PET is found if the resistance to heat transfer (r_h) decreases more than 50% from the 100 $s{\cdot}m^{-1}$. A 50% increase in r_h appears to cause only a 10% to 15% change in predicted PET. A constant r_h was used in our calculations; therefore, error between actual and predicted r_h does not affect irrigation control, because r_h, is not allowed to vary. A similar "sensitivity-curve" method was used by Barber (1984) to measure the influence of several parameters of the Cushman model used in predicting ion uptake by plant roots.

Preliminary tests. Data from a fall crop indicated no difference in fruit number or overall yield from the four treatments (Table 1). However, plant fresh weight was higher in treatments irrigated with variable solution EC. Increases in plant fresh weight reflected increases in the concentration of the irrigated nutrient solution. Plant dry weights from the four treatments were not significantly different. Moreover, the variable SMP setpoint treatment produced significantly lower average fruit weight than the other three treatments. Treatments receiving variable EC were irrigated with significantly higher EC solution concentrations averaged over the course of the experiment due -to decreases in PET. However, all treatments received less than one irrigation per day (Table 2). Drainage measurements indicated higher drainage volume for the variable EC treatment. Differences in drainage measurements between the four treatments were not significant, due in large part to the relatively infrequent measurements (n < 12). On many days, no drainage took place, but zero values were not included in the averages because we wanted to determine the actual quantity of solution when drainage occurred.

Conclusion

Crop irrigation requirements can be predicted accurately using electronic tensiometers to determine irrigation starting times, and PET estimates to determine water and nutrient requirements. Therefore, nutrient solution EC and irrigation timing can be varied to reflect current growing conditions better. Our system accomplishes both of these functions and improves the precision over systems currently avail-

Table 1. *Effects of varying nutrient solution electrical conductivity (EC) and peat substrate tension on yield of greenhouse tomatoes.*

Treatments		Yield parameters[z]				
SMP (kPa)	($dS{\cdot}m^{-1}$)	No. fruit (m^2)	Total yield ($kg{\cdot}m^{-2}$)	Plant flesh wt (g)	Plant dry wt (g)	Avg. fruit wt (g)
-5.0	2.5	40.7	3.98	775	72.9	98
-5.0	Variable	38.4	3.82	898**	82.3	100
Variable	2.5	42.4	3.70	798	75.6	87**
Variable	Variable	37.2	3.75	913**	80.7	101
	LSD	NS	NS	110**	NS	6.6**

[z]*Values are averaged over 12 replications. Tension was varied between -3.0 and –7.0 kPa and EC between 1 and 4 $ds{\cdot}m^{-1}$, according to calculated setpoints.*
***Significant at* $P \geq 0.01$.

Table 2. ***Irrigation and drainage measurements from peat-grown tomatoes irrigated with fixed and variable nutrient solution concentrations at fixed and variable substrate water potential setpoints..***

Treatments		Irrigation data[z]					
		Irrigation			Drainage		
SMP (kPa)	EC ($dS \cdot m^{-1}$)	Liters / plant	EC ($dS \cdot m^{-1}$)	pH	Liters / bag	EC ($dS \cdot m^{-1}$)	pH
–5.0	2.5	1.12	2.22	5.69	1.44	3.21	5.93
–5.0	Variable	1.14	2.84**	5.76	3.06	3.40	5.76
Variable	2.5	1.27	2.30	5.78	2.13	2.69	5.90
Variable	Variable	1.21	2.75**	5.74	2.27	3.46	5.77
	LSD	NS	0.50**	NS	NS	NS	NS

[z]*Measurements were taken daily from each treatment. Variable treatments were as follows: $-3.0 \geq$ SMP ≥ -7.0 kPa and/or $1 \geq$ EC ≥ 4 $dS \cdot m^{-1}$, according to calculated setpoints.*
***Significant at* P ≥ 0.01.

able for irrigation management, especially those varying nutrient solution EC according to seasonal changes in crop water and nutrient demand. Results from preliminary experiments indicate that tensiometer–PET technologies can improve irrigation management in tomatoes growing in peat-based substrates. Irrigation regimes can therefore be changed automatically for different days or seasons to reflect changing environmental conditions influencing plant growth and development. The flexibility of this system enables it to be used under wide-ranging greenhouse environmental conditions.

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Hot-water Treatment and Indole-3-butyric Acid Stimulates Rooting and Shoot Development of Tropical Ornamental Cuttings

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Additional index words. heat treatment, propagation, auxin, *Anthurium*, *Cordyline*, *Dracaena*, *Gardenia*, *Plumeria*

Summary. Frangipani (*Plumeria* hybrid 'Donald Angus') cuttings immersed in hot water (49C for 10 min) followed by 0.8% indole-3-butyric acid (IBA) basal treatment (hot water + IBA) had greater root length and weight compared to the nontreated control, hot water, or IBA treatment alone. Greater percentage of rooting and number of roots per cutting were observed for hot-water-treated + IBA-treated cuttings compared to the nontreated control and hot-water treatment alone. In a second study, *Dracaena fragrans* (L.) Ker-Gawl. 'Massangeana', *D. deremensis* Engl. 'Warneckii', *D. deremensis* Engl. 'Janet Craig', *D. marginata* Lam., and cape jasmine (*Gardenia jasminoides* Ellis) cuttings displayed results similar to those observed with *Plumeria* cuttings. In addition to enhancing rooting, hot water + IBA also stimulated

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