

Water Relations of Melon (*Cucumis melo*) Plants in Soilless Culture

MOHD RAZI ISMAIL and FAUZI MUHAMMAD

Department of Agronomy and Horticulture

Faculty of Agriculture

Universiti Pertanian Malaysia

43400 Serdang, Selangor, Malaysia

Keywords: *Cucumis melo*, water availability, growth, relative water content, stomatal resistance, photosynthesis rate, yield

ABSTRAK

Tanaman tembikai wangi (*Cucumis melo*) di tanam didalam campuran gambut dan pasir dengan diberikan beberapa kepadatan air iaitu 25, 50, 166% dan muatan ladang. Isipadu air yang ditambah pada substrat adalah 300, 600, 2000 dan 1200 ml setiap hari menyamai keperluan air yang dinyatakan. Pertumbuhan vegetatif dan hasil berkurangan secara berkadar dengan kepadatan air. Pemberian air diatas paras muatan ladang substrat menghasilkan pertumbuhan dan hasil yang tinggi disebabkan tanaman mengubahsuaikan pengaruh evaporasi tinggi didalam iklim mikro. Jumlah bahan terlarut didalam buah meningkat cepat semasa perkembangan buah didalam keadaan kepadatan air rendah. Peningkatan kepadatan air memperbaiki status air daun, respon stomata dan kadar fotosintesis. Pada tahap kepadatan air yang rendah, pengurangan status air daun menyebabkan kadar fotosintesis mengurang sehingga mencapai nilai negatif pada akhir perkembangan tanaman. Perkaitan di antara status air daun dan rintangan stomata di hasilkan dan dibincang berdasarkan pengaruh hidrolitik dan tanpa hidrolitik terhadap stomata.

ABSTRACT

Melon (*Cucumis melo*) plants were grown in a peat and sand mixture under water availability of 25, 50, 166% and field capacity. The respective amount of water added to substrate was 300, 600, 2000 and 1200 ml per day. Vegetative growth and yield decreased proportionately according to water availability. Overwatering above substrate field capacity resulted in the highest growth and yield as the plants compensated for the influence of high evaporative demand in the microclimate. Total soluble solids in the fruit increased rapidly during fruit development under reduced water availability. Increased water availability improved leaf water status, stomatal response and photosynthesis rate. At lowest water availability, a reduction in leaf water status caused photosynthesis rate to decline and to reach negative values by the end of the growth period. A relationship between leaf water status and stomatal resistance was established and is discussed with reference to hydraulic and non-hydraulic causes controlling stomatal responses.

INTRODUCTION

Cultivation of crops using soilless culture in a protected environment has proven beneficial compared to open field cultivation (Mohd Razi 1994). An important feature in the management of aggregate soilless culture is to optimise production through efficient use of water and nutrients. As plants grown in soilless culture are normally grown in a protected structure, changes in plant microclimate, especially temperature

and humidity, can subject them to water stress, as measurable by various indicators including leaf water potential, relative water content, hydraulic resistance and transpiration rate. Most physiological processes are affected by the water status of a plant (Hsiao 1973). The relationship between leaf water status and plant physiological processes needs to be established for efficient irrigation management, especially when available water is scarce. Schulze (1994) indicated that in

sunflower, the daily water loss from leaves may be equivalent to several times their total fresh weight under conditions of open stomata and high photosynthesis rates. In contrast, a plant water deficit equivalent to only a small fraction of its total fresh weight would cause severe metabolic disorders due to water stress.

In the present study, the sensitivity of melon plants to the changes in water status of plants grown in a peat:sand mixture in a protected environment was investigated relating to growth, physiological processes and yield.

MATERIALS AND METHODS

The experiment was conducted in the Hydroponics Glasshouse Unit at Universiti Pertanian Malaysia. Throughout the experiment, the mean maximum air temperature was $33.6 \pm 5.7^\circ\text{C}$ and the mean minimum temperature was $26 \pm 2.1^\circ\text{C}$; mean day relative humidity was $56 \pm 6.2\%$. The plants were generally grown at an atmospheric vapour pressure deficit of 2.3 ± 0.5 kPa.

Seeds of melon (*Cucumis melo*) cv Birdie were sown in compost. After 14 days seedlings were transferred to polybags containing 10 kg of a peat and sand mixture (3:1 peat:sand). The seedlings were grown in the mixture for a further 2 weeks with regular watering before uniform plants were chosen.

Four irrigation regimes were used in the experiment. Field capacity, determined as the moisture held by the substrate after free drainage for 24 h, was 0.12 g water/g substrate. The irrigation regimes were 25, 50 (restricted watering), 100 (field capacity) and 166% (overwatering) of field capacity arranged in a completely randomized design with 4 replicates. The respective volumes of water added to the substrate every day were 300, 600, 1200 and 2000 ml. The plants were fertilized with the constituents of Cooper formulation (Cooper 1979) at 20CF. Other standard management procedures for melon cultivation were followed (Mohd Razi 1994).

Dry matter accumulation was assessed from seven sequential destructive samplings. At each sampling, four plants were selected at random from each treatment except the guard rows. During each harvest, the plants were fractionated into the following parts: leaves, stems, roots and fruit. Leaves were enclosed in polythene bags for leaf area determinations using an automatic

leaf area meter (Delta-T Cambridge, UK). All samples were dried to constant weight for at least 48 h in a forced draught oven at 80°C .

Relative water content, stomatal diffusive resistance and photosynthesis rate were determined 1, 3, 5 and 7 weeks after each treatment. Relative water content was determined according to Barrs and Weatherley (1962). Stomatal resistance was measured with a diffusion porometer (MKIII, Delta-T Devices Ltd, Cambridge, UK) on the mature leaves which were exposed to full sunlight and which were adjacent to leaves sampled for relative water content. Leaf photosynthesis rate of attached leaves was measured using a portable infrared gas analyser (ADC2-The Analytical Development Co. Ltd, Hoddesdon, UK) on the same leaves as used for the diffusive resistance measurements. For each treatment, at least four readings were taken from different leaves. Measurements were made 4-5 h after sunrise when PFD was between $750-860 \mu\text{mol m}^{-2}\text{s}^{-1}$.

Fruit dry weight accumulation was followed by sequential harvesting. Total soluble solids were determined on each of the harvested fruit using a hand refractometer. The experiment was terminated when fruits on the plants reached maturity, determined by small cracks at the base of the fruits.

RESULTS

Plant Vegetative Growth

Fig. 1 shows the dry matter accumulation in leaf, stem and root parts of melon plants as influenced by different water availability. Leaf dry weight increased proportionately to the available water in the substrate. In general, leaf dry matter accumulation of plants receiving 2000 ml water was 4-6, 12-18, and 14-22 g higher than in plants receiving 1200, 600 and 300 ml water, respectively. The difference between treatments was noticeable by the third week of growth. Similarly, stem dry weight was higher in the plants receiving 2000 ml water per day, while differences between plants receiving water less than 1200 ml was not apparent after the 4th week. The difference in root dry weight of plants receiving 2000 ml was apparent by the first week, but no difference was registered between plants receiving less than 1200 ml of water each day. The differences between plants receiving 1200 and 600 or 300 ml water were only apparent by the fifth week. Root growth of plants receiving

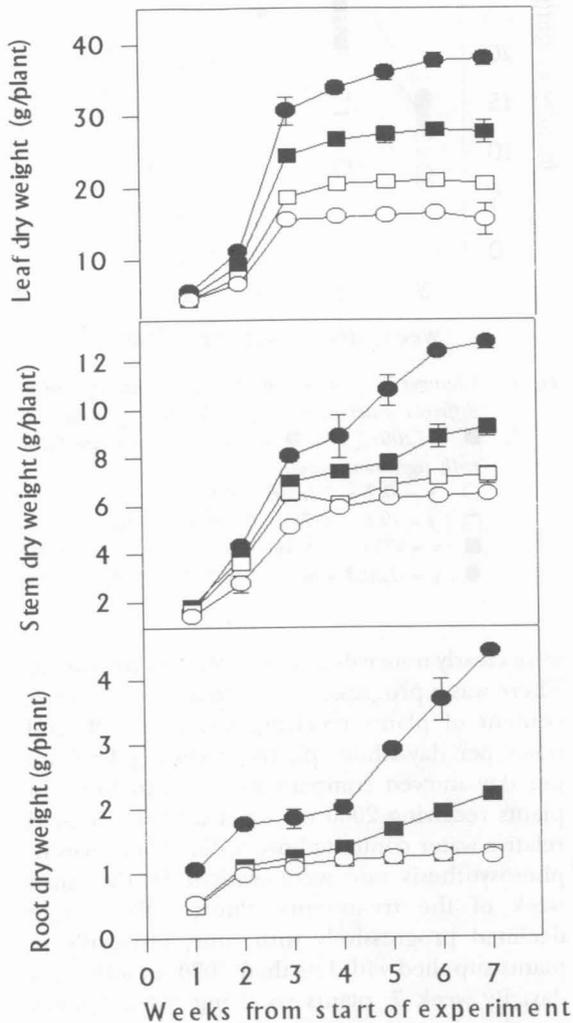


Fig 1: Leaf, stem and root dry weight of melon plants grown in different water regimes. ○ = 300ml; □ = 600ml; ■ = 1200ml and ● = 2000ml. Values given are means of ± SE of 4 replicates. Some SE marks reside within symbols

less than 1200 ml water was almost constant throughout the growth period. At final harvest, root dry matter accumulation in plants receiving 2000 ml water per day was twice and four times higher than plants receiving 1200 and 600 or 300 ml, respectively.

Fig. 2 shows the relationship between leaf area and the duration of plants under various water regimes. In general, the relationship was almost sigmoidal for the two parameters, except for plants receiving 300 ml water. The reduction in leaf area by the end of the growth period was due to senescence of the older leaves during fruit maturity. At the period of maximum growth, the leaf area of plants receiving 2000 ml water was 1.3, 2 and 5 times greater than for plants receiving 1200, 600 and 300 ml, respectively

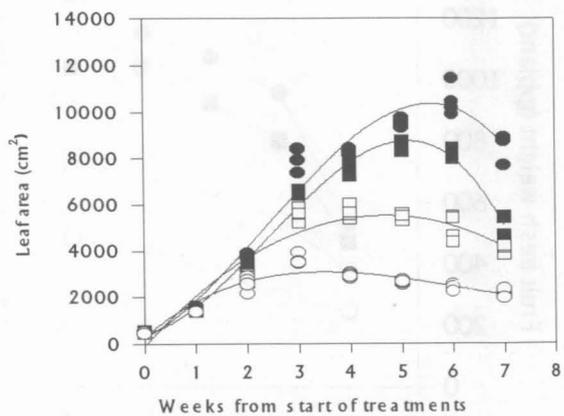


Fig 2: Leaf area of melon plants as influenced by different water regimes. Lines are fitted with regression equation: ○ = 300ml; $y = 282.3 + 1853x - 375.8x^2 + 1x^3$; $r^2 = 0.88$
 □ = 600ml; $y = -112.0 + 2400x - 256.2x^2$; $r^2 = 0.91$
 ■ = 1200ml; $y = 400.0 + 522.2x + 748.4x^2 - 104.0x^3$; $r^2 = 0.98$
 ● = 2000ml; $y = 257.8 + 1090.6x + 583.4x^2 - 81.5x^3$; $r^2 = 0.96$

Fruit Development

Fig. 3 shows changes in total soluble solids and fresh weight of fruits exposed to different water regimes. The differences in total soluble solids values between treatments were only apparent by the fifth week. A reduction in water availability to the plants increased the total soluble solids content of fruit. Fruit fresh weight was consistently higher on plants receiving 2000 ml water. At final harvest, fresh weight of fruit from plants receiving 1200, 600 and 300 ml was 15, 42 and 70% respectively, lower than plants receiving 2000 ml water. The change in fruit

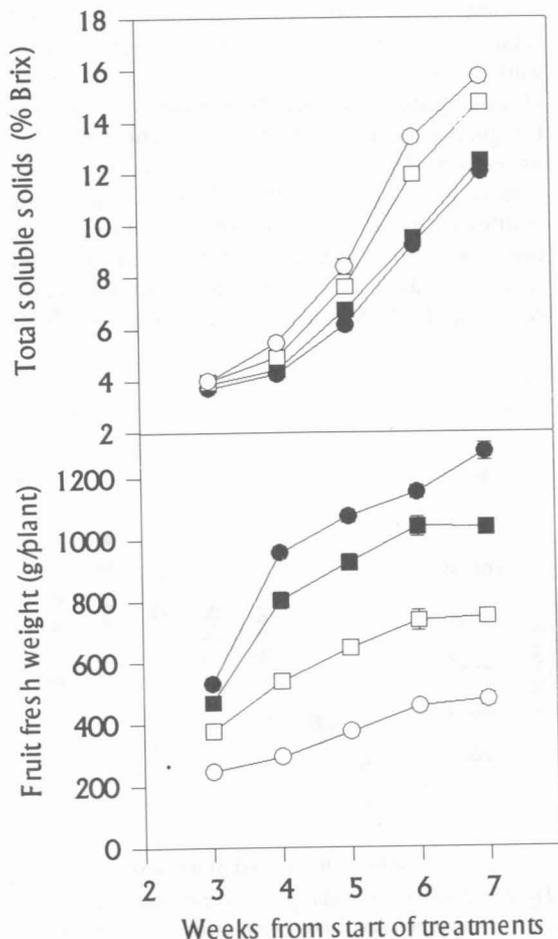


Fig 3: Fruit growth and total soluble solids of melon plants exposed to different water regimes. ○ = 300ml; □ = 600ml; ■ = 1200ml and ● = 2000ml. Values given are means of ± SE of four replicates. (Most SE marks reside within symbols)

dry weight followed a similar pattern (Fig. 4) and there was also a close correlation between the accumulation of dry matter in the fruit and the duration of treatments.

Relative Water Content, Stomatal Resistance and Rate
Changes in stomatal resistance, relative water content and photosynthesis rate are illustrated in Fig. 5. Stomatal resistance was increased with reduced water availability. Plants provided with only 300 ml water per day showed a marked increase in stomatal resistance and displayed complete stomatal closure by the fifth week. Reducing water availability resulted in decreased relative water content of leaves; the differences

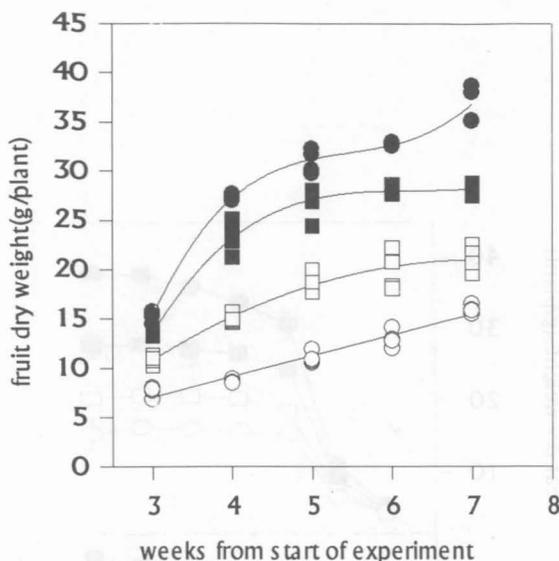


Fig 4: Changes in fruit growth of melon plants exposed to different water regimes. ○ = 300ml; □ = 600ml; ■ = 1200ml and ● = 2000ml. Lines are fitted with regression equations:
○ : $y = 0.7 + 2.1x; r^2 = 0.95$
□ : $y = -9.8 + 8.75x - 0.6x^2; r^2 = 0.93$
■ : $y = -73.6 + 48.6x - 7.7x^2 + 0.4x^3; r^2 = 0.97$
● : $y = -120.3 + 80.7x - 14.5x^2 + 0.9x^3; r^2 = 0.98$

were clearly noticeable after 3 weeks of treatment. There was a progressive decline in relative water content of plants receiving less than 1200 ml water per day while plants receiving 1200 ml per day showed comparable values to those of plants receiving 2000 ml water and maintained relative water content above 85%. Differences in photosynthesis rate were evident by the third week of the treatments. Photosynthesis rate declined progressively with time, especially in plants supplied with less than 2000 ml water per day. By week 7, plants receiving 300 ml water per day showed a negative leaf photosynthesis rate.

DISCUSSION

As reported for several other plant species (starfruit; Mohd Razi *et al.* 1994; pepper, Aloni *et al.* 1991; tomatoes, Mohd Razi *et al.* 1993), reduced water availability in melon plants retards vegetative growth and fruit development. This is particularly evident for plants grown under high temperature with low air humidity conditions, which often results in high atmospheric vapour pressure deficits in the plant microclimate.

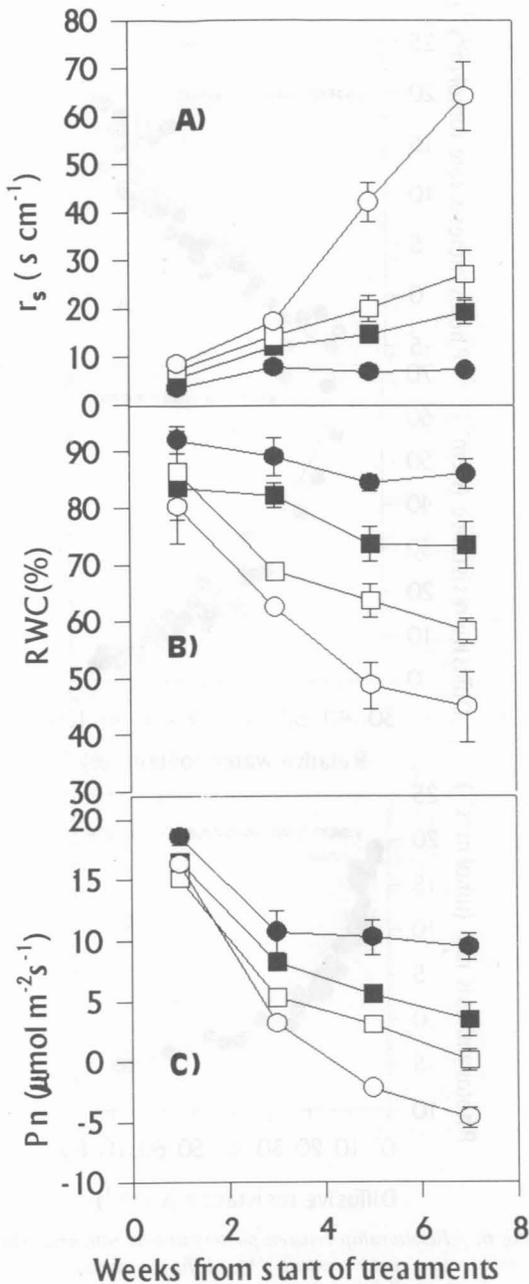


Fig 5: Stomatal diffusive resistance, R_s (A), relative water content, $RRWC$ (B) and photosynthesis rate, P_n (C) of melon plants as influenced by water regimes. ○ = 300ml; □ = 600ml; ■ = 1200ml and ● = 2000ml. Bars represent SE with 4 replicates, some marks reside within symbols

have demonstrated in this study that irrigating plants to field capacity level (1200 ml water) under similar conditions also resulted in a decrease in dry matter accumulation after 3 weeks. Further reductions in water availability to the plants have resulted to a decrease in leaf and root growth. Leaf area expansion, particularly, was greatly reduced in plants receiving 1200 ml or less water compared to 2000 ml water per day.

It has been reported by many workers that the primary effect of slight to moderate water stress is either at the cell extension phase or at both the cell division and cell extension phases of leaf growth depending upon the plant species. (Acevedo *et al.* 1971; Schulze 1986; Jefferies 1989). We have shown that leaf area expansion in melon plants receiving adequate water followed a sigmoidal growth response consisting of three phases of growth i.e an acceleration phase, a linear growth phase and a senescent phase with the older leaves dying. Early cessation of leaf area expansion was observed on the plants grown under reduced water availability (Fig. 2). This could be due to an early disruption of metabolic activities associated with cell expansion. The causes of reduction in leaf area expansion could be associated with either hydraulic and/or non-hydraulic mechanisms. The hydraulic process is associated with changes in turgor pressure which act as a driving force for cell expansion and hence leaf growth (Acevedo *et al.* 1971; Begg and Turner 1976; Dale 1988). Non-hydraulic signals generated from roots growing under reduced water availability have been reported to directly inhibit effect on leaf growth in the absence of detectable shoot water deficit as related to the latter mechanism (Passioura 1988; Gowing *et al.* 1990). Zhang and Davies (1991) have proposed that abscisic acid plays the role of a chemical signal in root to shoot communication and can bring about a retardation of leaf growth in plants grown at reduced water availability.

The study also demonstrated the importance of water availability for fruit development. The reduction in fruit growth is a common response in plants exposed to reduced water availability (Blanco *et al.* 1989; Batten *et al.* 1994), though some other researchers showed a beneficial regulated deficit irrigation in perennial fruit (Mitchell and Chalmers 1982; Van den Ende *et al.* 1987). Adam (1990), working with tomatoes,

Smith (1989), working with oil palm, argues that such conditions would limit production even if plants were grown under adequate moisture. We

reported a decrease in fruit growth but an increase in fruit total soluble solids under reduced water availability conditions prevailing on peat moss. This fruit fresh weight and total soluble solids pattern is also observed in the present study (Fig. 3).

Photosynthesis rate decreased with decreasing water content (Fig. 6) so that respiration appears to exceed photosynthesis rate when relative water content was reduced to less than 60%. Under such conditions, stomatal diffusive resistance also showed a substantial increase. Although the role of guard cell turgor in regulating stomatal closure could be a causative factor for this phenomenon, the effect of non-hydraulic signals cannot be ruled out. If leaf internal water status solely influenced stomatal closure, there would be a clear linear relationship between these two parameters. The correlation analysis shows such linearity only when relative water content is low, so that there must be another factor triggering early stomatal closure during slight or undetectable changes in leaf water status (Fig. 6). The responses of stomata to a root signal may be regarded as a feedforward response, in which roots in dry soil produce a chemical signal to reduce water loss even before plants experience internal water deficits (Schulze 1994). However, this chemical signal controlling the root-shoot communication has yet to be identified. According to Davies *et al.* (1994), there seems to be quite compelling evidence for a central role for abscisic acid in chemical signalling between roots and shoots in controlling stomatal responses. Some other workers, however, disagree (Munns and King 1988; Trejo and Davies 1991).

This biphasic evidence on leaf internal water status and stomatal resistance observed in the present study with melon plants needs to be further examined to ascertain the role of hydraulic and non-hydraulic factors influencing plants under conditions of water stress. The relationship between stomatal resistance and rate shows a drastic (50%) reduction in photosynthesis rate is coincident with even a small increase in stomatal resistance from 4.5 to 10 s cm⁻¹. It is speculated that photosynthesis apparatus may be inhibited before any effect on the stomatal apparatus. The influence of such stomatal and non-stomatal factors in regulating rates has also been reported by other workers (Ogren and Oquist 1985; Ephrath *et al.* 1993). The present study further

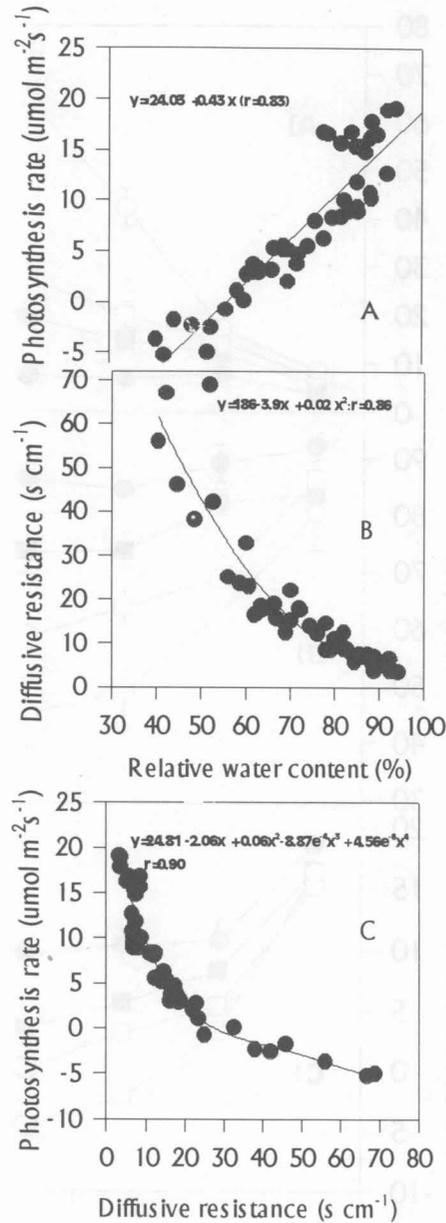


Fig 6: Relationship between photosynthesis rate and relative water content (A), diffusive resistance and relative water content (B) and diffusive resistance and photosynthesis rate (C) of melon plants exposed to different water regimes

shows that when stomatal resistance increased to more than 20 s cm⁻¹, photosynthesis rates declined to negative values. This threshold value is particularly important in future studies to improve water use efficiency of melon plants under reduced water availability.

ACKNOWLEDGEMENTS

We thank IRPA Hydroponic Group of Faculty of Agriculture, Universiti Pertanian Malaysia for funding this project. We also thank Roslan Parjo and Ismail Idris for their technical assistance.

REFERENCES

- ACEVEDO, E., T.C. HSIAO and D.W. HENDERSON. 1971. Immediate and subsequent growth responses of maize leaves to change in water stress. *Plant Physiology* **48**: 31-36.
- ADAM, P. 1990. Effects of watering on the yield, quality and composition of tomatoes grown in bags of peat. *Journal of Horticultural Science* **65**: 667-674.
- ALONI, B., J. DAIE and L. KARNI. 1991. Water relations, photosynthesis and assimilate partitioning in leaves of pepper (*Capsicum annum L.*) transplants: Effect of water stress after transplanting. *Journal of Horticultural Science* **66**: 75-80.
- BARRS, H.D and P.E. WEATHERLEY. 1962. A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Science* **15**: 413-428.
- BATTEN, D.J., C.A. MCCONCHIE and J. LLOYD. 1994. Effects of soil water deficit on gas exchange characteristics and water relations of orchard lychee (*Litchi chinensis* Sonn.) trees. *Tree Physiology* **14**: 1177-1189.
- BEGG, J.E. and N.C. TURNER. 1976. Crop water deficits. *Advances in Agronomy* **28**: 161-217.
- BLANCO, M.S., A. TORRECILLAS, A. LEON and F.D. AMOR. 1989. The effect of different irrigation treatments on yield and quality of Verna lemon. *Plant and Soil* **120**: 299-302.
- COOPER, A.J. 1979. *The ABC of NFT*. London: Grower Books.
- DALE, J.E. 1988. The control of leaf expansion. *Annual Review of Plant Physiology and Plant Molecular Biology* **39**: 267-295.
- DAVIES, W.J., F. TARDIEU and C.L. TREJO. 1994. How do chemical signals work in plants that grow in drying soil? *Plant Physiology* **104**: 309-314.
- EPHRATH, J.E., A. MARANI and B.A. BRAVDO. 1993. Photosynthetic rate, stomatal resistance and leaf water potential in cotton (*Gossypium hirsutum* L.) as affected by soil moisture and irradiance. *Photosynthese* **29**: 63-71.
- GOWING, D.J., W.J. DAVIES and H.G. JONES. 1990. A positive root sourced signal as an indicator of soil drying in apple, *Malus domestica* B. *Journal of Experimental Botany* **41**: 1535-1540.
- HSIAO, T.C. 1973. Plant responses to water stress. *Annual Review of Plant Physiology* **24**: 519-570.
- JEFFERIES, R.A. 1989. Water stress and leaf growth in field grown crops of potato (*Solanum tuberosum* L.). *Journal of Experimental Botany* **40**: 1373-1381.
- MITCHELL, P.D. and D.J. CHALMERS. 1982. The effect of reduced water supply on peach tree growth and yield. *Journal of American Society of Horticultural Science* **107**: 853-856.
- MOHD RAZI, I. 1994. *Pengeluaran Tanaman Hidroponik*. Kuala Lumpur: Dewan Bahasa dan Pustaka.
- MOHD RAZI, I., M.S. HALIMI and K. JUSOH. 1993. Growth and yield of tomatoes as influenced by different substrate, substrate volume and irrigation frequencies. *Acta Horticulturae* **342**: 143-153.
- MOHD RAZI I., S.W. BURRAGE, H. TARMIZI and M.A. AZIZ. 1994. Growth, plant water relations, photosynthesis rate and accumulation of proline in young carambola plants in relation to water stress. *Scientia Horticulturae* **60**:101-114.
- MUNNS, R. and R.W. KING. 1988. Abscisic acid is not the only stomatal inhibitor in the transpiration stream. *Plant Physiology* **88**: 703-708.
- OGREN, E. and G. OQUIST. 1985. Effects of drought on photosynthesis, chlorophyll fluorescence and photoinhibition susceptibility in intact willow leaves. *Planta* **166**: 380-388.
- PASSIOURA, J.B. 1988. Roots signal control leaf expansion in wheat seedlings growing in drying soil. *Australian Journal of Plant Physiology* **15**: 687-693.
- SCHULZE, E.-D. 1986. Whole plant responses to drought. *Australian Journal of Plant Physiology* **13**: 127-141.
- SCHULZE, E.-D. 1994. The regulation of plant transpiration: Interactions of feedforward, feedback, and futile cycles. In *Flux Control in Biological Systems*, ed. E.-D. Schulze p. 203-237. New York: Academic Press.
- SMITH, B.G. 1989. The effects of soil water and atmospheric vapour pressure deficit on stomatal behaviour and photosynthesis in oil

palm. *Journal of Experimental Botany* 40: 647-651.

ZHANG, J and W.J. DAVIES. 1991. Changes in the concentration of ABA in xylem sap as a function of changing soil water status can account for changes in leaf conductance and growth. *Plant, Cell and Environment* 13: 277-285.

TREJO, C.L. and W.J. DAVIES. 1991. Drought-induced closure of *Phaseolus vulgaris* stomata precedes leaf water deficit and any increase in xylem ABA concentration. *Journal of Experimental Botany* 42: 1507-1515.

VAN DEN ENDE, B., D.J. CHALMERS and P.H. HERIE. 1987. Latest development in training and management of fruit tree crops on Tatura trellis. *HortScience* 22: 561-568.

(Received 16 February 1995)

(Accepted 28 February 1996)