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Growth, Plant Water Relation and Photosynthesis Rate of Young *Theobroma cacao* as Influenced by Water Stress

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ABSTRAK

Kesan daripada jangkamasa kekangan air terhadap tumbesaran dan perubahan fisiologi pokok koko muda, Theobroma cacao *telah dikaji. Pemberian air dibuat selang 4, 8, dan 12 hari selama 20 minggu. Luas daun, indeks luas daun, berat kering daun, akar dan batang didapati berkurangan dengan bererti dengan jangkamasa penahanan pemberian air. Terdapat kaitan yang rapat antara kadar fotosintesis dan perubahan potensi air daun. Kadar fotosintesis daun menjadi kurang apabila potensi air daun jatuh dibawah paras -2.0 MPa. Penentuan proses fisiologi menunjukkan variasi yang nyata antara tiga klon tempatan iaitu KKM4, KKM5 dan KKM25 dengan KKM25 menunjukkan potensi air daun, konduksi stomata dan kadar fotosintesis daun yang paling tinggi.*

ABSTRACT

The effects of duration of water stress on the growth and physiological changes of young Theobroma cacao *plants were investigated. Water was withheld for 4, 8, and 12 days before rewatering for a period of 20 weeks. Leaf area, leaf area index, leaf, root and stem dry weights were significantly reduced with duration of withholding water. There was a close relationship between photosynthesis rate and changes in leaf water potential. Leaf photosynthesis rate was reduced when leaf water potential dropped below -2.0 MPa. Determinations of plant processes showed a clear variation between three local clonal plants i.e. KKM 4, KKM 5 and KKM 25 with KKM25 recording the highest leaf water potential, stomatal conductance and leaf photosynthesis rate.*

INTRODUCTION

Water status of the plant is one of the important factors that determine rate of survival of young cacao *(Theobroma cacao)* plants at the establishment stage. The importance of water management of the crop has generated interest in the plantation sector to invest in drip-system irrigation (Lim *et al.* 1991). Basic information on plant responses to water relation should be understood in order to optimize the usage of such systems.

It has been well acknowledged that water availability can affect plants through a wide range of developmental and physiological processes. The reduction in growth and development of cacao plants as influenced by reduced water availability was shown earlier by Sale (1970). Levels of internal water status in the plant which affect stomatal functioning and photosynthesis activity vary widely with plant species (Hsiao *et al.* 1976). When plants are exposed to water deficit the degree of limitation of stomatal closure depends on the intensity of water stress which is normally indicated by the level of leaf water potential and relative water content in the plant.

At present little information is available on these responses in cacao plants. Experiments were carried out to analyse the physiological attributes under reduced water availability. The relationship between physiological processes in the plant is also analysed in order to determine the level of water status in plants affecting photosynthesis rate.

MATERIALS AND METHODS

The experiments were done on young cacao plants under rainshelter at Agronomy Research Unit, Universiti Pertanian Malaysia.

Experiment 1:

Five-month-old seedlings of UIT1 x Na32 were grown in pots containing 13 kg of soil of the Munchong series to which 40 g of triple superphosphate was added. The experimental crop was surrounded by two guard rows and sheltered from rain by a polyethylene-film cover. This shelter reduced light transmission by at least 45%, which is within the suitable range for early growth of cacao in the field (Wessel 1985).

Amounts of water applied were based on the field capacity predetermined by the gravimetric method. Watering treatments were applied at intervals of 0, 4, 8 and 12 days over a period of 20 weeks. The experiment was conducted in a completely randomized design with 5 replications. After the 20-week cycle of stress and rewatering, dry weights of leaves, stems and roots were recorded after ovendrying at 105°C for 16 hours. Leaf area was determined by leaf area meter.

Experiment 2.

Six-month-old budded plants of Malaysian Agricultural Research Institute (MARDI) clones KKM4, KKM5 and KKM25 were used. The choice of clone was based on the vegetative growth screening as discussed by Jalil (1990). Water was withheld for 3, 7 and 14 days prior to the water relation and gas exchange measurements.

Leaf area index was monitored by a plant canopy analyser (LiCor 2000 Nebraska U.S). Net assimilation rate and relative growth rate were determined by destructive sampling at two consecutive dates and calculated according to formulae given by Hunt (1982). Leaf water potential was measured using a pressure chamber (PMS Instr. Oregon, U.S.A) to indicate the water status in plants. Relative water content was determined according to Weatherley (1950). A transient state porometer (Delta-T Cambridge U.K) was used to determine the changes in diffusive resistance in the first experiment. A closed system of an infrared gas analyser (ADC Hoddesdon, UK) was used for the gas exchange determinations. 4-5 leaves were sampled for the determinations.

RESULTS AND DISCUSSION

The results showed the plant vegetative growth characters were significantly reduced ($P<0.05$) with the reduction in water availability (Table 1). A reduction of almost 50% in root, stem and leaf dry weight was observed with 12 days of withholding water. The sensitive response of cacao to water availabilty was evident by the significant reduction ($P<0.05$) in the leaf, root and stem dry weight even when water was withheld for only 4 days. There were also significant reductions in leaf area index, net assimilation rate and relative growth rate with increasing durations of withholding water (Table 2). These results were consistent with the suggestion that cacao is highly sensitive to water stress as growth reduction occurs with a slight change in plant water status (Sale 1970; Alvim and Alvim 1978). Furthermore, the results shown in Table 3 suggested that plant water status was affected after only 4 days of withholding water. In young star fruit *(Averrhoa carambola)* grown under similar environmental conditions and soil volume, leaf water potential and relative water content were only significantly reduced ($P<0.05$) when water was withheld for 7-10 days (Ismail *et al.* 1991). The results showed that relative water content was reduced to half that of the control treatment coincidental with the reduction in leaf growth of plants receiving the least amount of water.

Diurnal variation of stomatal resistance, leaf water potential and environmental variables are shown in Fig. 1. The lowest leaf water potential was recorded at T4 which dropped to -2.3 MPa at midday. Similarly, diffusive resistance was greatest at T4 reaching 35 s cm-1 indicating stomatal closure. The figure clearly shows that stomatal closure occurred at midday, which coincided with the highest radiation levels and highest air temperature. Both leaf water potential and diffusive resistance were significantly highest and lowest ($P<0.05$) respectively in the daily watering treatment. There was no significant difference in diffusive resistance between T1 and T2 indicating that watering at four-day intervals did not affect the stomatal responses as compared to daily watering. However leaf water potential was signifi-

TABLE 1
Effect of duration of withholding water on plant vegetative growth.

Days of withholding water	Plant dry weight (g) Total	Roots	Stem	Leaves	Plant height (cm)	Root density (cm3)
0	41.83[a]	11.64[a]	10.27[a]	19.92[a]	25.0[a]	43.0[a]
4	32.86[a]	9.12[b]	8.14[b]	15.60[b]	20.8[b]	37.0[b]
8	27.16[b]	7.62[bc]	6.80[bc]	12.74[bc]	17.4[c]	19.9[c]
12	20.59[c]	5.15[bc]	5.84[c]	9.80[c]	15.7[d]	12.0[d]

Mean separation by DMRT at 5% level. Average of 5 replications.

TABLE 2
Relative growth rate (RGR), net asssimilation rate (NAR) and leaf area index (LAI) as influenced by duration of withholding water

Duration of withholding water (days)	RGR $g.g^{-1}$	NAR $10^{-3}g.\ cm^{-3}$	LAI Unit
0	0.33[a]	2.51[a]	2.24[a]
4	0.32[a]	2.24[ab]	2.04[b]
8	0.31[b]	2.21[b]	1.96[b]
12	0.29[c]	1.99[c]	1.73[c]

Means separation by DMRT 5%. Means of 5 replications.

TABLE 3
Leaf water potential (μw), relative water content (RWC), stomatal conductance (gs) and photosynthesis rate (Pn) as influenced by duration of withholding water.

Duration of withholding water (days)	μw (MPa)	RWC (%)	gs mms^{-1}	Pn $(umol/m^2/s)$
0	-0.80[a]	95.03[a]	3.4[a]	4.32[a]
4	-1.52[b]	83.64[b]	2.9[ab]	4.79[a]
8	-2.24[c]	70.93[c]	2.5[b]	3.37[b]
12	-2.93[d]	55.15[d]	1.1[c]	-0.08[c]

Means separation by DMRT at 5%. Average of 4 replications

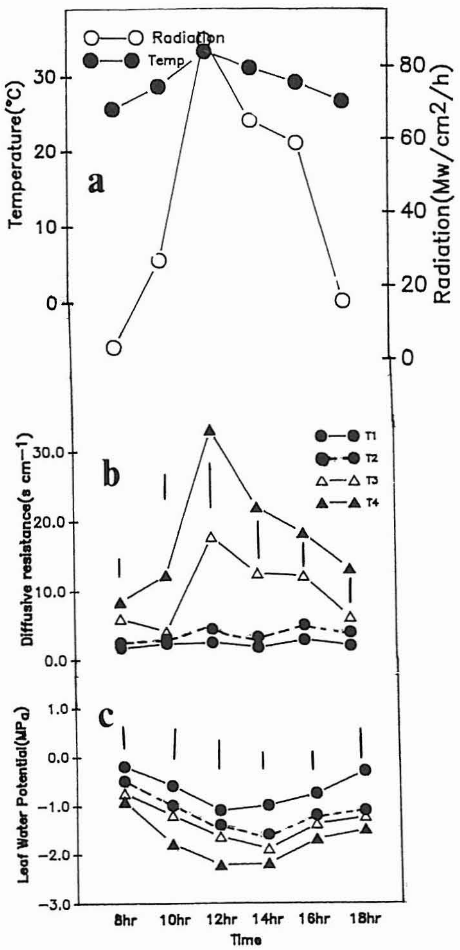

Fig. 1: Diurnal variation in radiation and temperature (a), diffusive resistance (b) and leaf water potential (c) as influenced by duration of withholding water. T1: 0; T2: 4 days; T3: 8 days and T4: 12 days. Bars represent LSD 5%

cantly lowered (P<0.05) at T2 compared to daily watering after midday. The study also suggested that stomatal response was closely related to the changes in water relations in the plants. Stomata are sensitive to plant water status and tend to close as leaf water potential decreases. Results showed that the onset of stomatal closure began when water potential dropped below -1.8MPa. In another study, Hutcheon (1977) showed that stomatal resistance of cacao increased rapidly when water potential fell below -1.5 MPa. In peach, Garnier and Berger (1987) indicated that the onset of the stomatal closure occurred when the threshold value of water potential was reached. Ackerson and Herbert (1981) suggested that stomata closure in response to soil water deficit is through the mediation of water potential. A whole range of stomatal adaptation to the changes in leaf water potential in several crop species was discussed by Jones (1986). However, there are also reports that stomatal conductance can be reduced without water potential mediation (Bates and Hall 1981). In a study to this effect, stomata responded directly to changes in vapour pressure deficit independently of leaf water potential (Schulze 1986). This study showed that reduction in the photosynthetic rate was observed only when water potential dropped below -2.0 MPa are *(Fig. 2)*. In corn, Barlow *et al.* (1977) showed that photosynthesis and transpiration rates are affected when the reduction of water potential in plants is less than -1.2 MPa. They indicated that water stress affects leaf elongation more than photosynthesis rate. In this study, although diurnal leaf elongation was not monitored, there was a tendency to leaf growth reduction when water was withheld for 4 days (Table 1) but net assimilation and photosynthesis rates were not affected *(Fig. 2*; Table 3). Hsiao *et al.* (1976) suggested that CO_2 assimilation was reduced when water potential was greater than -1.0 MPa but cell growth was inhibited when water potential dropped slightly below -0.5MPa.

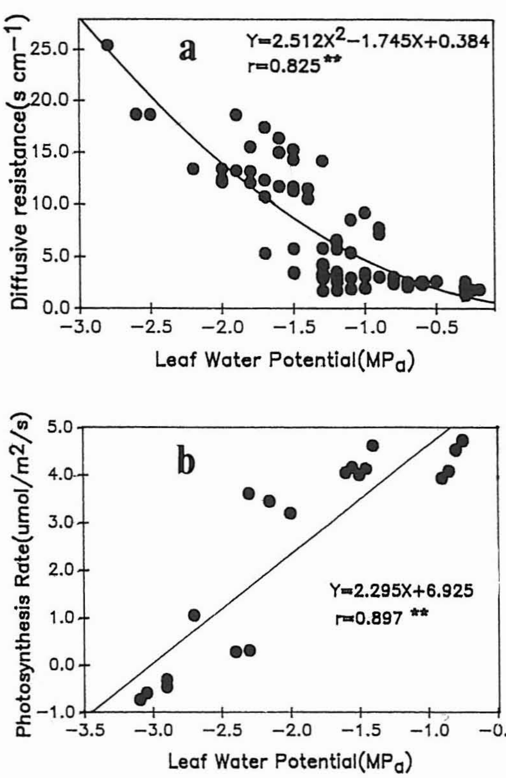

*Fig 2: Relationship between leaf water potential and diffusive resistance (a) and photosynthesis rate (b). **: Significant at P = 0.01*

Variable results were observed between clonal plants in relation to the changes in leaf water potential, stomatal conductance and photosynthesis rate *(Fig. 3)*. Clone KKM25 showed higher leaf water potential, stomatal conductance and photosynthesis rate compared to the other two clones rate studied during the stress period. Leaf water potential of KKM25 declined to -1.78 MPa but with KKM4 and KKM5, leaf water potential dropped to -2.3 MPa and -2.2 MPa respectively. There were no significant interactions ($P>0.05$) between clone and stress period on stomatal conductance and photosynthesis rate. Withholding water significantly reduced ($P<0.01$) both plant processes, similar to the results obtained from the first study. The fact that KKM25 clone exhibited better plant physiological responses supported the evidence that clone KKM25 can tolerate water stress (Jalil 1990). Appropriate irrigation management must be considered if clone KKM4 or KKM5 is to be planted commercially, especially in drought-prone areas.

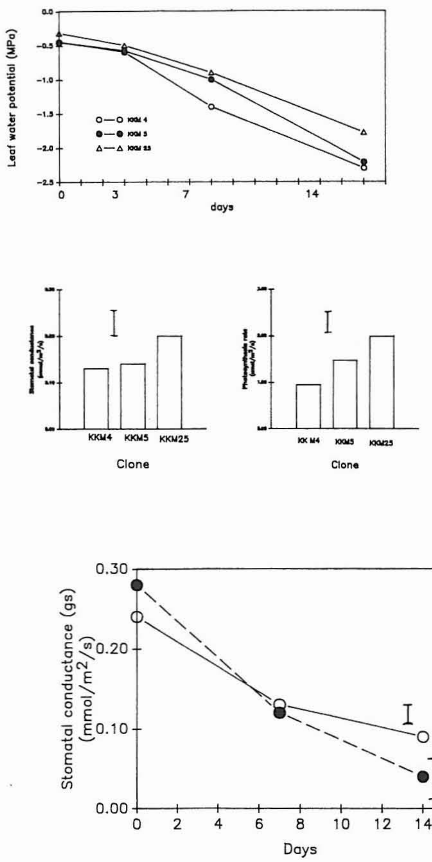

Fig. 3: Effects of duration of water stress on the changes in leaf water potential, stomatal conductance (gs) and photosynthesis rate (Pn) of three KKM cacao clones. Bars represent LSD 5%.

CONCLUSION

The sensitivity of young cacao plants to water stress was evident from the reduction in plant vegetative growth attributed to changes in plant physiological processes. At low leaf water availability, stomata tended to close, which resulted in the reduction of leaf photosynthesis rates. An understanding of these relationships is essential for achieving efficient irrigation management in cacao establishment in the field.

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