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Diurnal and seasonal patterns of water potential, photosynthesis, evapotranspiration and water use efficiency of clusterbean

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Abstract

Diurnal patterns of leaf water potential (Ψ_W), canopy net photosynthetic rate (P_N), evapotranspiration rate (E), canopy temperature (T_c), and water use efficiency (WUE) of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub., cv. Desi] were studied at six phenological stages of plant development under field conditions at CCS Haryana Agricultural University, Hisar. The highest P_N, E, and WUE were observed at pod initiation stage (61 DAS). Daily maxima of P_N were usually between 11:00 to 14:00 h while those of E and WUE between 12:30 and 16:00 h. P_N was mainly dependent on photosynthetically active radiation and E on air temperature (T_a) but the relationships varied at different growth stages. WUE declined with the increase in T_a. At mid-day, Ψ_W was highest during pod initiation.

Additional key words: air and leaf temperature; *Cyamopsis tetragonoloba*; photosynthetically active radiation; water relations.

Introduction

During the last decade, the influence of photosynthetically active radiation and temperature on daily patterns of tissue water relations, P_N, E, and WUE at different growth stages in wheat, maize, sorghum, pearlmillet, chickpeas, and *Brassica* species have been studied in north-western India (Singh *et al.* 1985, 1986, 1987a,b,c, 1993, Kumar *et al.* 1987, 1994, 1995, 1996, 1998, Yadav *et al.* 1987, 1990, Kumar and Elston 1992, Chaudhary *et al.* 1995, Singh and Singh 1995). It is important to

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evaluate and analyse these characters for each crop species, so that the information can be used for an improved understanding and management of crop-environment interactions and ultimately for obtaining higher yields.

Clusterbean is an important summer legume in north-western India. It is grown on marginal sandy soils that have been left unseeded due to the late onset of monsoon rains. We are not aware of any reports on its water relations or gas exchange. This paper reports ontogenic variations in these physiological characters in clusterbean grown under rainfed conditions.

Materials and methods

A field experiment on clusterbean [*Cyamopsis tetragonoloba* (L.) Taub., cv. Desi] was conducted at CCS Haryana Agricultural University, Hisar, India (29°10'N, 75°45'E). The soil was sandy loam in texture, alkaline in reaction (pH 8.1), and medium in fertility (available N, P_2O_5, K_2O in upper 30 cm soil profile was 18, 0.75, and 20 g m^{-2}). The crop was sown on 17 July after the beginning of the monsoon rains and the soil contained 124 mm of water in the top 100 cm profile at seeding time. The average bulk density of the upper metre of the soil profile was 1.44 kg m^{-3}. Per 1 m^3, 20 g N + 5 g P_2O_5 + 5 g K_2O was applied at seeding as urea, single superphosphate, and potassium chloride, respectively. The crop received 12 mm of rainfall 71 d after sowing (DAS) and 26 mm after 93 DAS.

Measurements of plant water relations (T_c, Ψ_W), canopy P_N, E, and WUE were made between 08:30 to 18:30 h on clear days (except after 12:30 at pod initiation stage when solar radiation was below average due to cloudy conditions) during six stages of plant development: 24 DAS (appearance of ten leaves on main stem), 53 DAS (flower initiation), 61 DAS (pod initiation), 70 DAS (50 % pod formation), 86 DAS (completion of pod formation), and 96 DAS (80 % of pod filling). Canopy P_N and E were simultaneously measured in three replicate plots using a closed canopy gas exchange system. The beginning CO_2 concentration was always near ambient air concentration, and the set value was about 20 g m^{-3}. Portable clear polythene (0.6 mm) chambers that were 60×60×120 cm during the vegetative period and 200×150× 200 cm at all the other occasions were used. Two fans were attached to each chamber to ensure complete mixing of CO_2 and H_2O during the measurements. This helped to eliminate the effects of boundary layer resistance of leaves. The chambers were temporarily placed over the plot for less than 60 s. Air samples drawn continuously from the chamber were passed through the CO_2 and water analysers and returned to the chamber. The CO_2 concentration was measured with a differential analyzer (*225 Mark II, Analytical Development Co.*, Hoddesdon, UK) and water vapour concentration with a hygrometer (*American Instrument*, Silver Springs, USA) as described by Kumar *et al.* (1994). Photosynthetically active radiation (PAR, 400-700 nm) above the crop canopy was measured with a quantum sensor (*Lambda Instruments*, Lincoln, NE, USA), and T_a by a telethermometer (*Thomas Scientific Appliance*, Philadelphia, USA). PAR decreased by 8 % inside the chamber. After 1 min of crop coverage, the T_a did not rise more than 1 °C. Therefore, outside T_a was

measured. Ψ_W was measured by the pressure chamber technique (Scholander *et al.* 1964), following precautions recommended by Turner (1988), T_c with an infrared thermometer (*Raynger II, Raytek,* USA) following Singh *et al.* (1985). WUE was calculated as P_N/E.

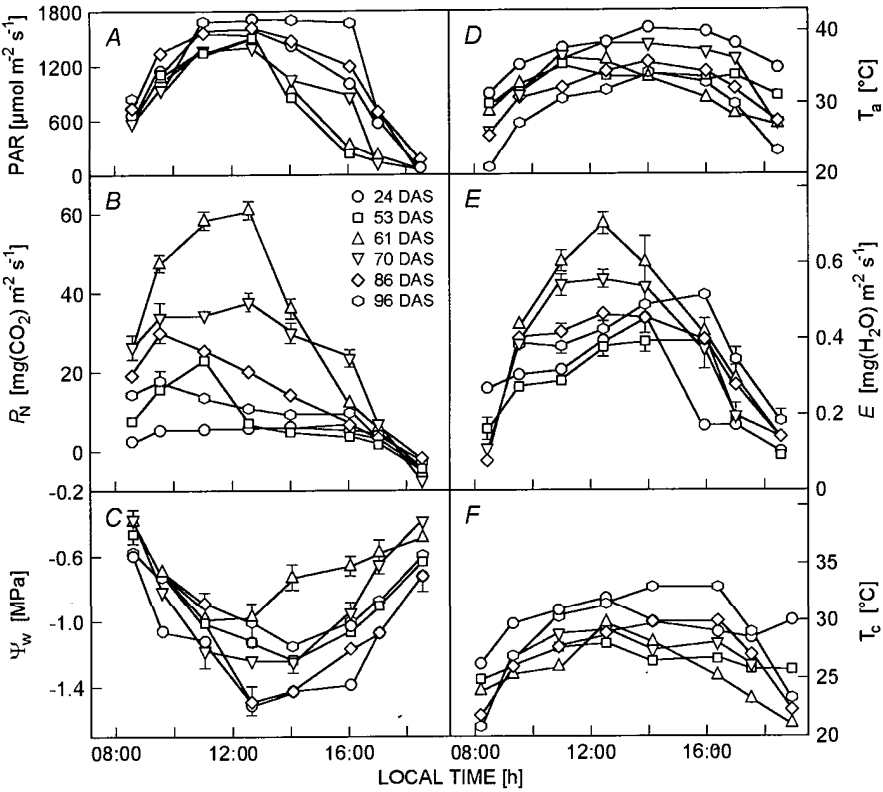

Fig. 1. Daily changes in (*A*) photosynthetically active radiation (PAR, 400 to 700 nm), (*B*) canopy photosynthesis (P_N), (*C*) leaf water potential (Ψ_W), (*D*) air temperature (T_a), (*E*) canopy temperature (T_c), and (*F*) evapotranspiration (*E*) of clusterbean at six stages of plant growth. The six stages were: 24 DAS (appearance of ten leaves on main stem), 53 DAS (flower initiation), 61 DAS (pod initiation), 70 DAS (50 % pod formation), 86 DAS (completion of pod formation), and 96 DAS (80 % filling of pods). The vertical bars in the figures represent the standard deviation of the means.

For total dry matter (TDM) studies, plants were harvested from an area of 0.5 m^2 at each occasion from the three replications. Before drying the samples in an oven at 65 °C, leaf area was determined with a portable area meter. At harvest, seed yield was determined separately for each plot.

Results and discussion

Leaf area index (LAI) of clusterbean reached a maximum (7.7) during pod initiation stage (61 DAS) and declined thereafter towards maturity (Table 1). LAI was low

Table 1. Leaf area index (LAI) and total dry matter (TDM) of clusterbean measured at six stages of plant growth [DAS]. Figures in parentheses are the standard deviations of mean of three replicates.

DAS	LAI	TDM [g m^{-2}]
24	2.03 (0.15)	58.67 (4.16)
53	6.20 (0.56)	331.33 (32.88)
61	7.70 (0.27)	636.00 (46.13)
70	5.03 (0.32)	714.67 (23.35)
86	1.93 (0.25)	863.33 (11.37)
96	0.43 (0.15)	881.00 (12.77)

during the pod formation and filling period (between 0.43 to 1.93). TDM increased at a faster rate until pod initiation (96 DAS). The increase in TDM after pod initiation did not coincide with LAI. It indicated that both pods and stem might have contributed to photosynthesis and thus to TDM after the start of leaf senescence. The seed yield was 175 g m^{-2} (1.75 t ha^{-1}).

P_N increased from the vegetative period (24 DAS), reached a maximum during pod initiation (53 DAS), and declined thereafter (Fig. 1*B*), but values were higher during the other reproductive stages than at 24 DAS. Daily maxima of P_N peaks at 24, 61, and 70 DAS were observed at mid-day (12:30), at 53 DAS at 11:00 h, and at 86 and 96 DAS before 09:30 h. A sharper decline in P_N was observed during the former than the latter growth stages in the afternoon. The decrease in P_N after 12:30 h at 61 DAS might be due to decrease in solar radiation (Fig. 1*A*) as a result of thin cloud cover in the aftemoon. Maximum P_N at 61 DAS was in agreement with maximum Ψ_W (Fig. 1*C*), LAI, and maximum requirements of photosynthates for pod initiation (Lush and Rawson 1979, Singh *et al.* 1993). Decline in P_N after pod initiation was perhaps due to decrease in leaf area and tissue Ψ_W coupled with higher T_a (Fig. 1*D*). An increase in PAR brought a linear increase in P_N but the response varied at different growth stages (Fig. 2*A*). The photosynthetic efficiency was highest at 61 DAS. The relationship between P_N and PAR in clusterbean was different from that of cereals, chickpeas, and *Brassica* species (Yadav *et al.* 1987, Singh *et al.* 1993, Kumar *et al.* 1994). In clusterbean, P_N peaked at 24, 61, and 70 DAS at mid-day, and at 53, 86, and 96 DAS in the morning hours, whereas in wheat and *Brassica species* it was attained at mid-day, between 12:00 to 14:00 h (Singh *et al.* 1993, Kumar *et al.* 1994).

The E followed the course of T_a but also seemed to be influenced by leaf area (Figs. 1*E*, 2*C*, Table 1). Maximum E was observed at 61 DAS followed by 70 DAS. This coincided with the peak of P_N. All other stages had more or less similar rates of E. Daily maxima of E were observed between 12:30 to 14:00 h at 61, 70, and 86 DAS, and between 14:00 and 16:00 h at stages 24, 53, and 96 DAS. Lower E observed at 24 and 53 DAS was mainly due to incomplete canopy development (LAI of 2.03), whereas at 86 and 96 DAS due to senescence. T_c was linearly and positively associated to T_a at all occasions except 24 DAS (Fig. 1*D*).

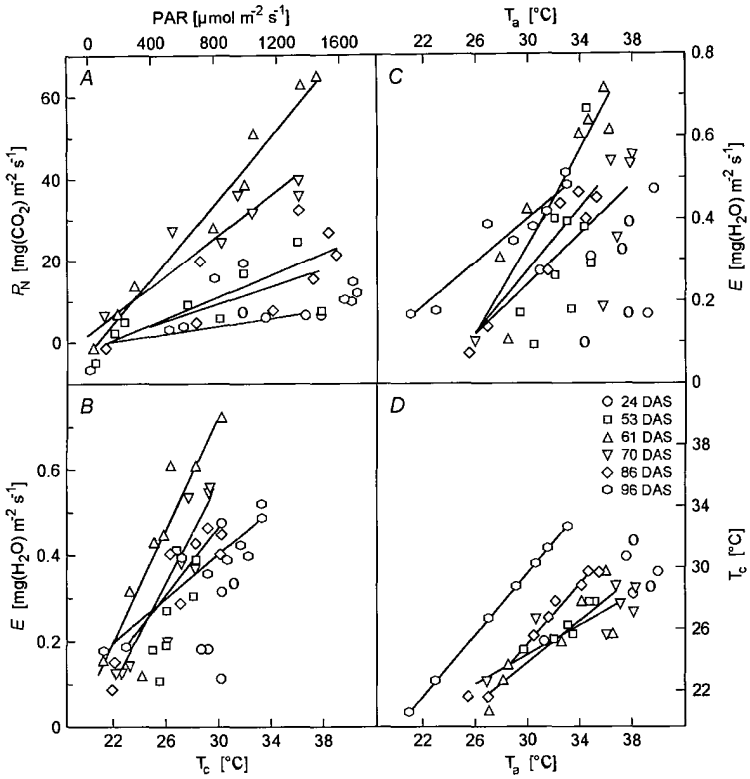

Fig. 2. Relationships between (*A*): net photosynthetic rate (P_N) and photosynthetically active radiation (PAR), (*B*): transpiration rate (*E*) and air temperature (T_a), (*C*): *E* and canopy temperature (T_c), and (*D*): T_a and T_c at various growth stages (see Fig. 1). Regression lines are shown only for the relations which are statistically signifcant ($p = 0.05$). Regressions for different growth stages are:

DAS		r^2		r^2
	A		*B*	
24	$P_N = -0.423 + 0.006$ PAR	0.808		
53	$P_N = -0.328 + 0.012$ PAR	0.568		
61	$P_N = -3.249 + 0.047$ PAR	0.978	$E_t = -1.314 + 0.055\ T_a$	0.863
70	$P_N = 1.811 + 0.030$ PAR	0.859	$E_t = -0.611 + 0.029\ T_a$	0.610
86	$P_N = -1.664 + 0.016$ PAR	0.538	$E_t = -0.830 + 0.037\ T_a$	0.838
96			$E_t = -0.398 + 0.027\ T_a$	0.918
	C		*D*	
53			$T_c = 9.537 + 0.520\ T_a$	0.822
61	$E_t = -1.336 + 0.069\ T_c$	0.793	$T_c = 4.533 + 0.658\ T_a$	0.751
70	$E_t = -1.318 + 0.063\ T_c$	0.820	$T_c = 10.655 + 0.469\ T_a$	0.792
86	$E_t = -0.756 + 0.041\ T_c$	0.836	$T_c = -1.432 + 0.960\ T_a$	0.975
96	$E_t = -0.398 + 0.027\ T_c$	0.918	$T_c = 0.000 + 1.000\ T_a$	1.000

WUE was highest at 61 DAS (Fig. 3*A*). Lower WUE recorded at 24 DAS was mainly due to lower P_N. It was different from that of other crops where higher E not P_N caused a decline in WUE (Singh *et al.* 1993, Kumar *et al.* 1994). Diurnally, WUE declined gradually from 08:30 till 16:00 h. The decline in WUE with the rise in T_a was different at various growth stages (Fig. 3*B*), maximum at 86 DAS was followed by those at 70 and 96 DAS.

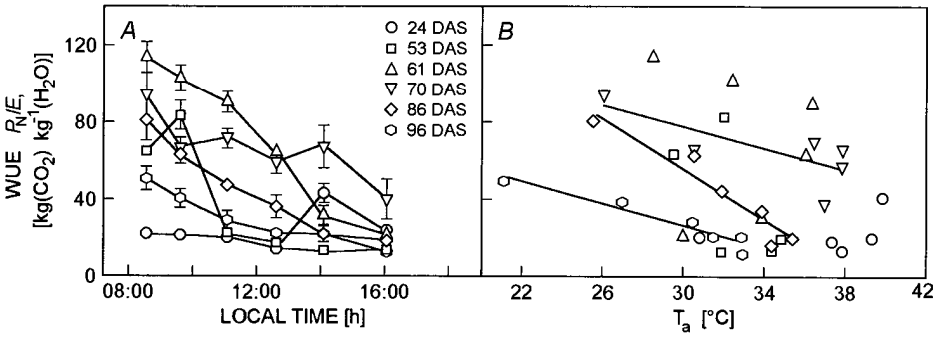

Fig. 3. (*A*) Daily changes in water use efficiency (WUE), and (*B*) relationship between WUE and air temperature (T_a). The vertical bars in the figures represent standard deviations of means. Regression lines are shown only for the relations which are statistically signifcant ($p = 0.05$). The regressions for some growth stages in *B* are: 70 DAS: WUE = 157.78 - 2.64 T_a, $r^2 = 0.52$; 86 DAS: WUE = 250.75 - 6.45 T_c, $r^2 = 0.92$; 96 DAS: WUE = 111.61 - 2.80 T_a, $r^2 = 0.91$.

In conclusion, the study highlighted that the daily and ontogenic variations in Ψ_W, P_N, E, and WUE in clusterbean were different from wheat, chickpea, maize, sorghum, pearlmillet, *Brassica* species, *etc.* In clusterbean, P_N and E was maximum during pod initiation period. P_N was mainly related to PAR, and E to both T_a and T_c. WUE was not associated with PAR but it was associated with T_a at late reproductive stages. Clusterbean shed all its leaves under severe water stress during the reproductive period, and started flowering and podding immediately after stress. Clusterbean, therefore, may be a successful legume under terminal drought conditions.

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