BRIEF COMMUNICATION

Irradiance influences tea leaf (*Camellia sinensis* L.) photosynthesis and transpiration

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Abstract

Rates of net photosynthesis (P_N) and transpiration (E), and leaf temperature (T_L) of maintenance leaves of tea under plucking were affected by photosynthetic photon flux densities (PPFD) of 200−2 200 µmol m^{-2} s^{-1}. P_N gradually increased with the increase of PPFD from 200 to 1 200 µmol m^{-2} s^{-1} and thereafter sharply declined. Maximum P_N was 13.95 µmol m^{-2} s^{-1} at 1 200 µmol m^{-2} s^{-1} PPFD. There was no significant variation of P_N among PPFD at 1 400−1 800 µmol m^{-2} s^{-1}. Significant drop of P_N occurred at 2 000 µmol m^{-2} s^{-1}. PPFD at 2 200 µmol m^{-2} s^{-1} reduced photosynthesis to 6.92 µmol m^{-2} s^{-1}. PPFD had a strong correlation with T_L and E. Both T_L and E linearly increased from 200 to 2 200 µmol m^{-2} s^{-1} PPFD. T_L and E were highly correlated. The optimum T_L for maximum P_N was 26.0 °C after which P_N declined significantly. E had a positive correlation with P_N.

Additional key words: leaf temperature; photosynthetic photon flux density.

The economic life of a tea plant under N.E. Indian conditions is around 40 years (Wight and Gokhale 1955). The tea plant passes through wide ranges of irradiance and temperature regimes which regulate its carbon assimilation. Most models of carbon gain as a function of photosynthetic irradiance assume an instantaneous response to increase and decrease of irradiance (Stoop *et al.* 1991, Wheeler *et al.* 1991). In the natural environment, most plants do not get continuous sunlight but experience its frequent fluctuation from full sun to shade caused by cloud cover, over-story shading, or within canopy shading (Knapp and Smith 1990). There exist also differences among metabolic characteristics of tea cultivars (Ponmurugan *et al.* 2007). The objective of this study was to establish the correlations among irradiance, rates of net photosynthesis (P_N) and transpiration (E), and leaf temperature (T_L), and to find out their optimum conditions in N.E. India.

Thirty clones of tea [*Camellia sinensis* (L.) O. Kuntze] cv. TV1 to TV30 were grown in the experimental plot of Tocklai Experimental Station (26º47′N, 94º12′E, and 96.5 m a.s.l.) without shade. The clonal tea plants were 30 years old, planted in single hedge at a spacing of 105×65 cm. NPK manuring was 120 N, 50 P, and 120 K [kg ha^{-1} y^{-1}]. All measurements were made on mature leaves fully exposed to sun at the top of the plucking table.

The measured atmospheric CO_2 concentration around the experimental site was 350 g m^{-3}. Photosynthetic photon flux density (PPFD) was measured on the plucking surface of tea bushes using the Portable Photosynthetic System (*CIRAS-1*, *PP Systems*). PPFD within 200−2 200 µmol m^{-2} s^{-1} and the corresponding P_N, E, and T_L were recorded twice in every month throughout the year both in bright sunny and cloudy days. One maintenance leaf from each of five individual plants of the 30 TV clones was selected at a time. On all occasions measurements were taken between 10:00 and 12:00 h. Data collected on 24 occasions from the 30 TV clones were pooled and arranged in ascending order of PPFD 200, 400, 600, 800, 1 000, 1 200, 1 600, 1 800, 2 000, and 2 200 µmol m^{-2} s^{-1}. Under natural environment, the PPFD fluctuated very frequently and it was difficult to get constant PPFD even for a very short

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period. The data were recorded only when P_N per unit area remained stable for a couple of minutes. Finally, 3 600 (30 clones×5 plants×24 occasions) field observed data were generated and 75 replications for each PPFD along with their corresponding physiological attributes on P_N, E, and T_L were pooled together. Thus the results presented in this paper are the averages of the 30 cultivars and each figure is the mean of 75 replications. All the data were statistically analyzed in which linear and quadratic coefficients were determined between the measured data.

At the lowest irradiance of 200 μmol m^{-2} s^{-1}, P_N was only 5.94 μmol(CO_2) m^{-2} s^{-1}. It increased significantly (p<0.001) with the increase of PPFD till it reached the saturation irradiance (SI) at 1 200 μmol m^{-2} s^{-1} (Fig. 1*A*). At this turning point (TP), maximum P_N was 13.65 μmol m^{-2} s^{-1}. The next higher assimilation was 12.08 μmol m^{-2} s^{-1} at 1 000 μmol m^{-2} s^{-1} PPFD. The difference between the two P_N was highly significant (p<0.001). At 1 400 μmol m^{-2} s^{-1} PPFD, P_N was 11.31 μmol m^{-2} s^{-1} which was significantly lower (p<0.001) than the maximum value. A gradual decrease of P_N occurred from 1 400 to 1 800 μmol m^{-2} s^{-1} PPFD, but the decrease was not significant. P_N at 2 000 μmol m^{-2} s^{-1} PPFD was 10.31 μmol m^{-2} s^{-1} which was significantly (p<0.001) lower than 11.41 μmol m^{-2} s^{-1} at 1 800 μmol m^{-2} s^{-1} PPFD. It was further reduced to 6.92 μmol m^{-2} s^{-1} at 2 200 μmol m^{-2} s^{-1} PPFD. P_N started decreasing from 1 275 μmol m^{-2} s^{-1} PPFD (Fig. 1*A*).

PPFD had a positive correlation (r^2 = 0.91) with T_L (Fig. 1*C*). T_L at 200 μmol m^{-2} s^{-1} PPFD was 16 ºC which increased significantly (p<0.001) at every 200 μmol m^{-2} s^{-1}. From 1 400 μmol m^{-2} s^{-1} PPFD, T_L increased significantly (p<0.001) till the highest recorded PPFD (Fig. 1*C*).

E increased linearly (r^2 = 0.94) with the increase of PPFD (Fig. 1*B*). The increase was highly significant (p<0.001) up to 1 000 μmol m^{-2} s^{-1} PPFD. After 1 200 μmol m^{-2} s^{-1} PPFD, E increased linearly up to 2 200 μmol m^{-2} s^{-1} PPFD.

The quadratic correlation coefficient curve (r^2 = 0.69) showed that P_N increased till E reached 5.0 mmol m^{-2} s^{-1} (Fig. 2*C*). E at 5.0 mmol m^{-2} s^{-1} was the turning point (TP) from which P_N declined. After TP, the P_N values were significantly reduced (p<0.001) with the increase of E (Fig. 2*C*).

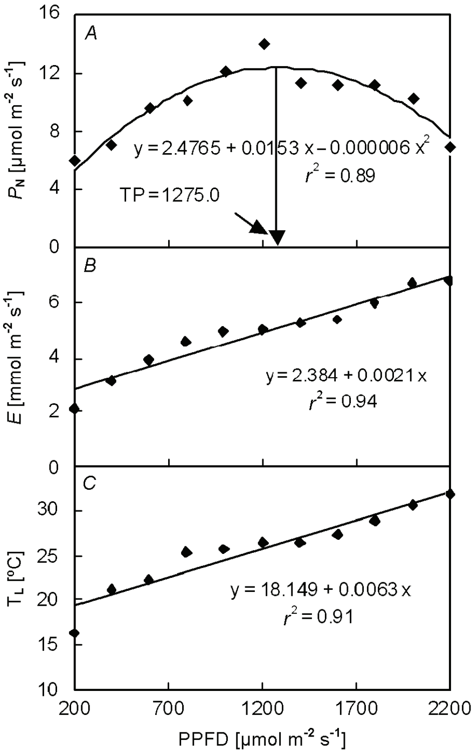

Fig. 1. Relationship between photosynthetic photon flux density (PPFD) and net photosynthetic (P_N) and transpiration (E) rates, and leaf temperature (T_L). Observed values (♦) and fitted curves or lines (—).

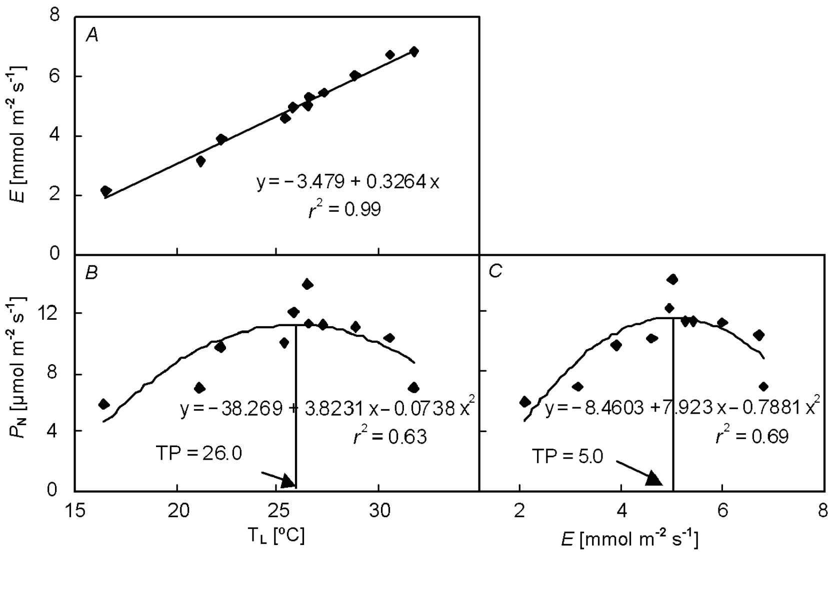

Fig. 2. Relationship between net photosynthetic (P_N) and transpiration (E) rates, and leaf temperature (T_L). Observed values (♦) and fitted curves or lines (—).

T_L had a positive correlation (r^2 = 0.99) with E (Fig. 2*A*). High T_L induced high E in tea leaf. Quadratic correlation coefficient curve (r^2 = 0.63) between T_L and P_N showed that P_N increased with the increase of T_L till it reached 26.0 ºC after which it started decreasing (Fig. 2*B*).

PPFD at 1 200 μmol m^{-2} s^{-1} was the optimum requirement for P_N in mature tea leaves exposed to sun. There was a significant increase of P_N between 1 000 and 1 200 μmol m^{-2} s^{-1} PPFD and significant decrease between 1 200 and 1 400 μmol m^{-2} s^{-1} PPFD (Fig. 1*A*). This indicates that tea plants under N.E. Indian conditions suffer from irradiance stress beyond 1 200 μmol m^{-2} s^{-1}. Under irradiance stress, the leaf is destabilized, which is followed by normalization and stability, when limits of tolerance are not exceeded and adaptive capacity is not overtaxed (Yordanov 1992). Thus in our investigation the limits of tolerance of tea leaves exceeded 2 000 μmol m^{-2} s^{-1} and overtaxed at 2 200 μmol m^{-2} s^{-1} PPFD.

Irradiance is the main controlling factor of P_N in tea leaves. SI for P_N was reported from different tea growing areas (Sakai and Aoki 1975, Squire 1977, Smith *et al.* 1993, Rajkumar *et al.* 1998, Mohotti and Lawlor 2002). At the highest elevation of Darjeeling hills (1 219 m a.s.l.) where the famous flavoury orthodox tea is produced, SI was 1 340 μmol m^{-2} s^{-1} PPFD (Ghosh Hajra and Kumar 1999). The topography and climatic conditions of Darjeeling hills are distinctly different from those of the plains of N.E. India.

In our investigation, P_N significantly increased from lower to higher PPFD till it reached the SI at 1 200 μmol m^{-2} s^{-1}. Because of the adaptive capacity of crops for P_N, SI varies from crop to crop. In N.E. India during the summer months of July to September, the PPFD is as high as 2 200 μmol m^{-2} s^{-1} which is detrimental for tea leaf photosynthesis. Thus 1 000 to 1 200 μmol m^{-2} s^{-1} can be the ideal PPFD for the growth of tea plants in N.E. India. Inter-planting of leguminous shade trees like *Albizzia chinensis* in tea fields for radiation interception was advocated by the tea growers even from the early days of the tea industry in N.E. India. Barman *et al.* (1994) further elaborated that shade significantly improved photosynthesis, partitioning of assimilates towards the pluckable shoots, shoot water potential, root starch reserve, chlorophyll (Chl) content, soil moisture, plucking point densities per unit area, and reduced E and photorespiration loss as well as leaf temperature and finally increased crop yield of tea. Interception of radiation at 20−30 % increased the yield of apple from 42 to 59 t ha^{-1} (Wiinche *et al.* 1996). Full sun (100 %) not only reduced P_N but also reduced the leaf, stem, and root dry mass (DM), shoot: root ratio, total leaf number, leaf area, DM per leaf, leaf Chl content, *etc*. (Anderson *et al.* 1991, Marler 1994).

There was a significant increase (p<0.001) of T_L in every hike of 200 PPFD, showing strong positive correlation (r^2 = 0.91) between the two factors of photosynthesis (Fig. 1*C*). Under ambient environments of N.E. India we found maximum P_N at T_L of 26.0 ºC. The fitted curve (Fig. 2*B*) of T_L showed the TP of P_N at 26.0 ºC. Above this temperature P_N declined. Optimum T_L for maximum P_N in tea varies between 25−30 ºC (Barua 1989). Hadfield (1968) reported that P_N sharply declined at T_L>35 ºC and between 39 and 42 ºC no P_N was found. Barman *et al*. (1993) reported a 23 % depression of tea leaf P_N due to high T_L (35 ºC) induced by high irradiance. We found at T_L of 32 ºC that P_N was reduced to 6.92 μmol m^{-2} s^{-1} (Fig. 2*B*). In the C_3 photosynthetic pathway of tea (Roberts and Keys 1978), the optimal T_L for P_N is below the thermal tolerance limit. There was no significant difference in P_N at the PPFD of 1 400−1 800 μmol m^{-2} s^{-1} where the corresponding T_L was 26.55−28.87 ºC. In tea, increase in T_L above the growth temperature of the plant generally results in a reduction of leaf photosynthetic metabolism (Barman *et al*. 1993). At high temperature the leaf tissues are irrevocably damaged which is commonly known as sun scorch of tea leaf.

PPFD had the positive correlation (r^2 = 0.94) with E (Fig. 1*B*). There was a highly significant difference (p<0.001) in E from lower to the next higher PPFD except between 1 000 and 1 200 μmol m^{-2} s^{-1} (p<0.05). Optimum E was 5.0 mmol m^{-2} s^{-1} for maximum P_N. The E at PPFD of 2 200 μmol m^{-2} s^{-1} was 7.0 mmol m^{-2} s^{-1} (Fig. 1*B*). Transpiration is one of the controlling factors for P_N. The quadratic correlation coefficient curve (r^2 = 0.69) for E and P_N (Fig. 2*C*) showed that P_N increased till E reached 5.0 mmol m^{-2} s^{-1}. E at 5.02 mmol m^{-2} s^{-1} became the TP for photosynthesis and above this value there was a significant (p<0.001) reduction in P_N. However, as E remained almost unaffected at the PPFD between 1 000 and 1 200 μmol m^{-2} s^{-1}, these two irradiances can be considered as optimum for the tea leaf photosynthesis. Again, at PPFD of 2 000−2 200 μmol m^{-2} s^{-1}, there was a marginal increase (p<0.05) in E but significant decrease (p<0.001) in P_N which indicated that at higher E a small difference drastically reduced P_N. The broad leaves of tea often exceed air temperature and have high E when exposed to full sunlight (Barman *et al.* 1993). Sun-exposed top mature leaves of tea transpire seven fold more water than the self shaded bottom leaves (Barman 1997). E can be reduced to 50 % by intercepting 30−50 % of full sunlight (Barman *et al.* 1994).

E was influenced by T_L and there was a strong positive correlation (r^2 = 0.99) between the two, *i.e.* E increased linearly with the increase of T_L (Fig. 2*A*). PPFD had a positive correlation with T_L (Fig. 1*C*) which had a direct correlation with E (Fig. 2*A*). The three major factors, viz. PPFD, T_L, and E are interrelated and control P_N. Any of the three factors exceeding the optimum level affects the process of photosynthesis. Thus the optimum PPFD at 1 200 μmol m^{-2} s^{-1}, T_L at 26 ºC, and E at 5.0 mmol m^{-2} s^{-1} yield maximum P_N. However, under ambient conditions these factors hardly coincide with optimum level. Thus, the actual yield of tea never touches the potential yield level. Therefore, the yield per hectare of this perennial crop is much lower than that of many other annual crops.

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