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SEASONAL VARIATION IN PHOTOSYNTHESIS AND PRODUCTIVITY OF YOUNG TEA

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SUMMARY

Photosynthetic rates (Pn) of China-type high quality tea (*Camellia sinensis*), clone T78, 44–68 months after field planting, were monitored during the different seasons of 1996 and 1997. The maximum value of Pn (11.9 μmol m^{-2} s^{-1}) was recorded in October when humidity was very high, temperature, sunshine hours and soil moisture were moderate and photosynthetic photon flux density (PPFD) was highest. Low temperature accompanied by low soil moisture reduced Pn during the winter (February). An important limiting factor for Pn was observed to be moisture stress. An apparent relationship between Pn and relative humidity was observed. In general, higher rates of Pn were recorded during periods of low evaporative demand (low VPD).

INTRODUCTION

The 'muscatel' flavour of Darjeeling tea (*Camellia sinensis*) holds a place of pride in the world but the average yield is only 650 kg ha^{-1} which is well below the all-India average of 1700 kg ha^{-1}. Apart from the old age of the plants and the high rate of vacancy, the hills offer various types of stress conditions, such as low temperature, low soil moisture in winter, most of the areas remaining foggy during the rainy season, high humidity and low levels of solar radiation, which are likely to affect growth and yield of tea significantly (Ghosh Hajra, 1992). Since it is the young vegetative shoots that are harvested from the tea bush, it has been presumed that productivity in tea is more directly linked to photosynthetic rate than in other perennial crops (Roberts and Keys, 1978). Squire and Callender (1981), however, suggested that tea yield is independent of current photosynthesis. Their observation was based on the low harvest index of tea, the fact that harvesting method can determine yield and the lack of correlation between shoot growth and photosynthetic rate in the short term.

This uncoupling of photosynthetic rate and shoot growth could be due to large soil water deficits (Stephens and Carr, 1991), high saturation deficits or low temperatures (Squire, 1979). When such constraints are removed at the onset of favourable growing conditions, carbohydrate reserves built up during the period of growth limitation can be mobilized to promote the growth of the emerging shoots (Hakamata and Sakai, 1980). In this way yield would be uncoupled from

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carbon assimilation in time, but not be completely independent of it (Smith *et al.*, 1993a).

The importance of carbon input in tea productivity can be appreciated from the fact that 95% of the dry weight of the plant is derived from photosynthesis (Banerjee, 1993). Therefore, an increase in net photosynthesis and more efficient partitioning are logical steps for increasing productivity. Plants under field conditions are exposed to a range of environmental, physico-chemical and biotic stress factors that show irregular and regular diurnal and seasonal variations (Levitt, 1980). A proper understanding of the influence of climatic variables on photosynthesis, leaf water potential and crop productivity is vital for any scientific planning of tea cultivation and also if physiological criteria are to be used as a part of a selection programme for superior genotypes. The present study investigates the influence of environmental variables on photosynthetic rate and yield of tea.

MATERIALS AND METHODS

Experimental site and plant material

The study was conducted at the Darjeeling Tea Research Centre, Kurseong (lat 26°55′N, long 88°12′E, altitude 1240 m). The topography is comprised of moderate slopes (25–30%). The top soil is about 45 cm in depth and the subsoil is stony. The soil is an Umbric Dystrochrept, moderately permeable, and moderately well drained. Infiltration rate is 4–6 cm h^{-1} measured by water hydrograph method in the field (unsaturated) conditions. The soil texture is sandy loam.

Healthy, 24-month-old transplants of Tukdah 78 (T78), a China-type high quality clone of commercial and scientific interest in the Darjeeling Hills, were planted on 20 June 1992. The experiment was set out with clonal main plots composed of two hundred plants per plot replicated five times. The plots were laid out at a double hedge spacing of 90 × 60 × 60 cm. Young plants which died were immediately replaced with healthy transplants of the same clone. The plants were mulched with Guatemala grass (*Tripsacum laxum*) in December 1993 and December 1994. The fertilizer programme broadly followed that recommended by the Darjeeling Tea Research Centre for the tea estates of the Darjeeling Hills. From the second year after planting onwards, 120 kg urea (46% N), 45 kg rock phosphate (20% P_2O_5) and 80 kg muriate of potash (58% K_2O) ha^{-1} were applied in May each year. In order to bring the tea into production earlier, the primaries/secondaries of the young plants were pegged by bending branches growing from the base of the plant outward and securing them into position with pegs made of pruned tea bushes or bamboo. The plants were not irrigated as this is the general practice in this region.

Photosynthesis of individual leaves

During 1996 and 1997, 44–68 months after field planting, net photosynthesis (Pn) was monitored three times a month at the beginning, middle and end of

February, April, June, August, October and December using a portable photosynthetic system (Li 6200, Li-Cor, Nebraska, USA) with a well mixed 390 cm^3 chamber as described (Li-Cor Inc., 1987). This portable instrument has internal programmes to calculate physiological quantities from measurements of air and leaf temperatures, humidity and CO_2 concentrations. Assimilation rates are computed in this instrument by assuming linear rates of change in water vapour and CO_2 concentrations within the leaf chamber. All data points during a measurement period were fitted using linear regression techniques. The humidity within the chamber was kept constant during the measurement period in order to get satisfactory results as observed by Leuning and Sands (1989). Dark-green healthy mature leaves at the surface of the canopy and fully exposed to incident sunlight were used for the observations. Such leaves are often referred to as 'maintenance' foliage. Four plants randomly selected from each of the five plots were assessed on every recording (200 readings). Efforts were made to ensure that measurements were taken only when there was no cloud cover. In a study of the diurnal fluctuations of Pn in different seasons it was observed that Pn was low in the morning, rose between 0900 and 1100 hours, showed a midday depression around 1300 hours and declined sharply after 1500 hours (Anonymous, 1996). In the present study Pn was measured between 0900 and 1100 hours when the maximum values of Pn were observed in the diurnal study. Photosynthetic photon flux density (PPFD) and vapour pressure deficits (VPD) were measured concurrently using the photosynthesis system three times a month at the beginning, middle and end of the month. Leaves were not brought into a horizontal position during measurement so as to avoid sudden change in incident quantum flux. The infra-red gas analyser had been recalibrated using compressed CO_2 gas immediately before the experimental work.

Leaf water potential (ψ_L) was measured simultaneously with Pn using a dewpoint hygrometer (Model C-52 sample chamber connected to an HR 33T microvoltmeter, Wescor Inc., Logan, USA) as described by Wescor Inc. (1988). Small circular leaf discs from the leaves on the opposite branches to those for Pn measurement were used and ψ_L values were expressed as megapascals (MPa).

Shoots (two leaves and a terminal bud) were harvested at weekly intervals between March and November (twenty-six cycles per year) from all the plots during the fourth and fifth year after field planting. Harvesting was carried out by the same pluckers throughout the season. The total fresh mass of the shoots from each plot was weighed at each harvest and converted to the made tea equivalent using a constant value of 0.22 (Anonymous, 1988). In the Darjeeling Hills, flushing of the tea crop starts at the end of March and after a sequence of production of normal leaves in April the shoot goes dormant for a short period during May. Thereafter, harvesting of the tea crop continues until September, declines considerably towards the end of October and then ceases during November until flushing starts again at the end of March.

The volumetric water content of the soil was determined gravimetrically in three replicates at two depths, 0–15 cm and 15–30 cm.

Simple correlations between the physiological and environmental variables were computed after pooling the respective data.

RESULTS

Since there were no significant differences between the values obtained for the various physiological and climatic variables in 1996 and in 1997, the values were grouped together and means of two years are presented.

Climate

The Darjeeling Tea Research Centre is located in the lower Himalayas. Owing to the subtropical situation, the year comprises a cold season (November to February), a hot season (March to May) and rains (June to August). The cold season is divided into two portions. The first, at the end of the rains, is mild and generally free from mist and cloud. This is the autumn. Towards the beginning of December frost can occur and sometimes in January the ground becomes extremely cold and the temperature goes down to 5 °C. Although there can be occasional falls of snow in January and February and air temperatures may fall below freezing point, no snowfall was experienced during the study.

Mean maximum air temperature ranges from around 15.8 °C in February to 23.5 °C in June and July; a mean minimum temperature of 5.9 °C was recorded in January (Table 1). A rapid increase in temperature takes place during March and

Table 1. Weather observations recorded at the meteorological observatory of the Darjeeling Tea Research Centre (lat 26°55′N, long 88°12′E, altitude 1240 m). Each value represents monthly average of 1996 and 1997.

	Months											
Parameters	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	14.7	15.8	19.3	22.8	22.7	23.5	23.5	23.3	22.6	20.7	19.4	16.6
Mean minimum temperature (°C)	5.9	8.4	11.5	15.1	16.2	18.3	18.4	18.9	17.4	14.9	12.4	10.2
Mean sunshine duration ($h\,d^{-1}$)	3.5	3.9	5.1	5.7	3.5	1.7	0.9	1.5	1.2	4.1	5.7	5.1
Mean relative humidity (%)	78.8	74.4	71.2	67.9	84.2	90.0	94.7	94.0	92.8	85.6	75.7	76.8
Total rainfall (mm)	30	15	28	43	228	738	990	746	549	102	0	11
Mean wind velocity ($km\,h^{-1}$)	3.6	4.0	4.0	5.3	5.3	5.4	5.3	4.4	4.3	4.2	5.0	4.3
Mean daily pan evaporation (mm)	5.2	6.3	6.7	6.9	5.0	3.6	3.4	3.4	3.9	4.2	5.0	5.4

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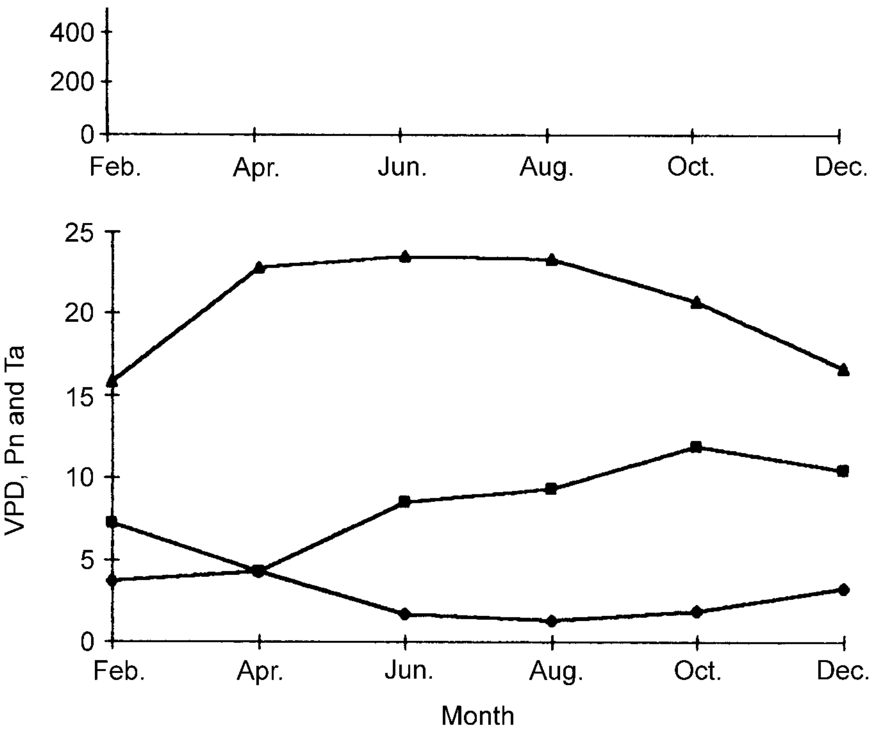

Fig. 1. The relationships between vapour pressure deficit (VPD, kPa —●—), photosynthetic photon flux density (PPFD, μmol $m^{-2} s^{-1}$ —— (7200 observations)), ambient temperature (Ta, °C —▲—) and net photosynthesis (Pn, μmol $m^{-2} s^{-1}$ —■— (7200 observations)) of the tea clone T78 during 1996 and 1997 at Darjeeling.

April owing to the warmer air from the plains. In May, the southerly winds reach the hills and cause increased precipitation which is at times very high. November and December are almost rainless and the light showers which fall in January and February occur when shallow depressions are passing eastward over the plains. In October, northerly winds begin, cloud is much less than in previous months and rainfall occurs, mainly owing to cyclonic storms which generally recurve towards north Bengal at the end of the season. Based on the agro-climatic conditions, the month of April is considered as pre-monsoon, June to August as monsoon, October to December as post-monsoon and February as winter. Further, December to April could be considered as a moisture-stress period.

The maximum irradiance (PPFD) was recorded in October (1340 μmol m^{-2}

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Table 2. Volumetric water content (%) in plots at the Darjeeling Tea Research Centre at the time of experimentation. Data are the averages of each month for 1996 and 1997.

Month	Top soil (0–15 cm)	Subsoil (15–30 cm)
February	20.7	21.9
April	23.9	25.4
June	33.1	34.3
August	32.2	34.1
October	30.8	31.9
December	28.1	29.9

s^{-1}) and decreased gradually in December and February. In April it increased (1320 μmol m^{-2} s^{-1}) and was very close to the October value (Fig. 1). An increase in VPD took place from December and it was maximal in April (4.3 kPa). The volumetric water content of both top and subsoils decreased gradually from October and declined rapidly during February (Table 2). The rate of pan evaporation also increased gradually from October until April.

Photosynthesis

The maximum value of Pn (11.9 μmol m^{-2} s^{-1}) was recorded in October (Table 3). During June and August, when the temperatures were almost equal to those in April, Pn increased. In April, June and August high temperatures prevailed but Pn was much lower in April than in June and August. Low temperature accompanied by low soil moisture during winter reduced Pn in February. In general, a linear relationship between ψ_L and the VPD of the atmosphere was observed. Pn, in general, decreased with lower ψ_L. VPD was higher in the dry months (December, February and April) than in wet months. The maximum value of Pn was recorded up to a VPD of 1.9 kPa; thereafter Pn

Table 3. Seasonal changes in photosynthetic rate (Pn) per unit leaf area (μmol m^{-2} s^{-1}) and leaf water potential (ψ_L) (MPa) with standard errors (s.e.) for the tea clone T78 during 1996 and 1997. Total samples for Pn and ψ_L per month were 600 and 60 respectively.

	Month						
Parameter	Feb.	Apr.	Jun.	Aug.	Oct.	Dec.	L.s.d season
Pn	7.2	4.3	8.5	9.3	11.9	10.4	0.92**
s.e.	0.67	0.26	0.43	0.62	0.53	0.41	
ψ_L	1.4	1.4	0.8	1.0	1.2	1.3	0.43**
s.e.	0.24	0.27	0.17	0.28	0.19	0.42	

**significant at $p = 0.01$.

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Table 4. Correlation coefficients among photosynthetic rate (Pn), air temperature (Ta), vapour pressure deficit (VPD), photosynthetic photon flux density (PPFD), leaf water potential (ψ_L) and yield of the tea clone T78 in Darjeeling.

Variables	Correlation coefficient (*r*)†
Pn and Ta	−0.92 n.s.
Pn and VPD	−0.66 n.s.
Pn and PPFD	−0.04 n.s.
Pn and ψ_L	0.33 n.s.
VPD and ψ_L	−0.86 n.s.
Pn and yield	−0.08 n.s.

†Significant at $p = 0.05$; n.s. = not significant.

declined slowly. When PPFD increased from lower intensities to about 1340 μmol m^{-2} s^{-1} in October, Pn increased but in April, when humidity and soil moisture were low, although the PPFD recorded was about 1320 μmol m^{-2} s^{-1}, very similar to the value recorded in October, the Pn value recorded was at its lowest.

The correlation coefficients among the environmental and plant factors are given in Table 4.

Yield

The annual yield of made tea was only 618 and 712 kg ha^{-1} in 1996 and 1997 respectively. There were also differences in the distribution of seasonal yield between the first two years (Fig. 2). High temperature, high soil moisture and moderate to high Pn were observed during June to October, but yield was highest in June and then gradually declined. Moderate yields were recorded in April in both years despite low soil moisture and a high rate of evaporation from the soil surface, but high air temperatures, high PPFD, and the highest sunshine hours occurred in April. No yield was recorded during the cold- and moisture-stress period from November until the end of March.

DISCUSSION

Climate

In view of the complex interactions between environmental variables and physiological processes it is very difficult to define a single set of optimum conditions for the growth of the tea crop. It has, however, been known for many years that temperature is considered to be cardinal to shoot growth (Carr, 1972) though the relationship between temperature and shoot growth varies according to the growing conditions. It is difficult to obtain a clear-cut relationship between

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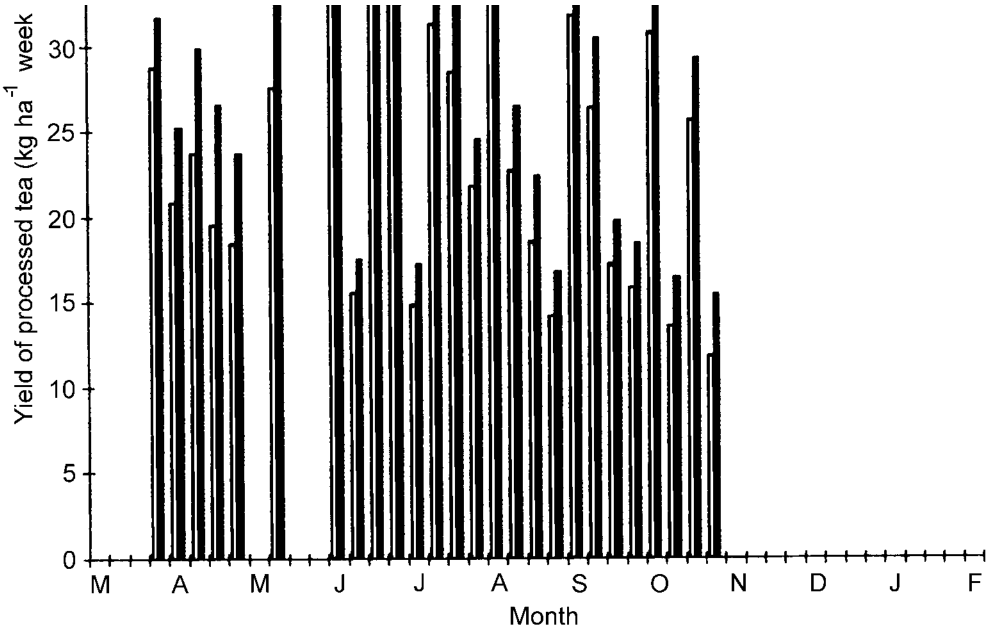

Fig. 2. Yield of processed tea (kg ha^{-1} week^{-1}) during 1996 (□) and 1997 (■). No harvest from November to February.

yield and mean daily temperature because of the synchronized flushing nature of the bush (Tanton, 1992).

Labedev (1961) reported a cessation of growth in Georgia when the mean air temperature fell below 13 °C. Nakayama and Harada (1962) did not observe any growth of potted tea plants in Japan when kept at a constant temperature of 12 °C. Carr (1972) reported a virtual cessation of growth of tea in southern Tanzania below a mean air temperature of 14 °C. Tanton (1982), using controlled environment facilities in Malawi, confirmed that the base temperature for shoot extension of clone SFS 150 was in the range of 12–13 °C. Thus, there is agreement between observations made in different parts of the world that extension growth of the tea plant ceases below a minimum temperature of 13 °C, but there is also some evidence of considerable clonal variation (7–15 °C) (Carr and Stephens, 1992). The rapid decline in yield in Darjeeling during October and then a cessation during November until the end of March indicates that low temperature is one of the major climatic variables limiting yield. Low temperature is also the vital factor causing low yields in the cold season in Malawi (Tanton, 1992). During the cold season only the old, slow-growing shoots would have remained on the bush but once the temperature started to rise in March a new generation of shoots would have started to develop. In Darjeeling the extension growth stops at monthly mean maximum and minimum temperatures of 19.4 and 12.4 °C respectively in November and it starts flushing at the end of March when mean maximum and minimum temperatures exceed 21 and 14 °C respectively. In Kenya the monthly mean maximum and minimum temperatures rarely exceed 24 and 11 °C respectively at any time of the year, but the tea plants flush throughout the year and produce annual yields of the same order as plants in many warmer regions (Barua, 1989).

In the present study, the higher yield was achieved during the period from June to September when the differences between maximum and minimum temperatures were least in comparison with the rest of the year. Hasan *et al.* (1965) achieved the best growth of tea in Bangladesh when the differences between maximum and minimum temperatures were least. Carr and Stephens (1992) observed that the minimum air temperature required to support shoot growth appears to be about 13 or 14 °C with an optimum in the range of 18 to 30 °C. In Darjeeling, the highest yield was achieved in June when mean maximum and minimum temperatures were 23.5 and 18.3 °C respectively.

Due to heavy and fairly well distributed rainfall in south India, Indonesia, Sri Lanka and other countries of South-East Asia, mean relative humidity rarely drops below 60% at any time of the year. Despite the unbalanced distribution of rainfall in north-east India and Darjeeling (71% of the annual rainfall occurs during June to August), mean relative humidity never drops below 60% in this region, even during the driest part of the year in March and April. In the northern latitudes of the former USSR and Japan atmospheric humidity remains fairly high (Barua, 1989). The situation is, however, different in many parts of Africa. In Malawi, during the hottest part of the year the saturation VPD may rise up to 45 mbar (equivalent to 4.5 kPa) (Ellis, 1971). However, temperature is not as high nor is humidity as low in the tea areas of Darjeeling as in Malawi where irrigation or misting would have to be more frequent in order to keep the leaf temperature low and humidity high during the hot and dry part of the year. Hadfield (1968) observed that high temperatures associated with high VPD inhibit tea growth in north India. In Darjeeling, higher temperatures in June and August were associated with lower values of VPD and, since the temperature was within the optimum range, highest yield was recorded in June. However, in April, the mean maximum temperature was equal to that in June but a higher VPD (4.3 kPa) was recorded and moderate yield was obtained.

Characteristics of photosynthetic rate

The maximum value of Pn (11.9 μmol m^{-2} s^{-1}) recorded in the present study was of the same order of magnitude as those reported for poplar and *Hevea* rubber by Singh *et al.* (1996) and Ghosh Hajra and Ghosh Hajra (1993) respectively. The lowest value of Pn recorded in April may be due to low humidity or moisture stress. There is abundant evidence in the literature that Pn is inhibited by water stress (Balasimha *et al.*, 1991; Sobrado, 1996). During the pre-monsoon (April) when the atmosphere was dry and plants were suffering from moisture stress, minimum Pn was recorded. In April, June and August higher temperatures prevailed but Pn was lowest in April when drought was coupled with higher VPD than in the wet months (June and August). The effect of temperature on the values of Pn obtained in different areas cannot be generalized because the optimum range of temperatures would vary depending on the overall environmental conditions of an area. Although the relationship between temperature and Pn can be defined in the laboratory, it is difficult to do so in the field where high temperature probably occurs with low leaf water potential. Sakai (1987) found a much lower temperature optimum for photosynthesis at 25 °C for laboratory-grown tea, although Hadfield (1975), also using laboratory-grown plants, found a temperature optimum at around 35 °C, with a rapid fall above 37 °C and no net uptake of CO_2 above 42 °C. In Kurseong, air temperature is never lethally high and was not a limiting factor for Pn. Unlike extension growth, photosynthesis does not stop at 13 °C. In Darjeeling, photosynthesis continued in the month of December to the third week of March when minimum temperature fell below 13 °C and the tea bushes were dormant.

With the onset of the monsoon rain in June the plants were able to recover fully from the water stress and an increase in the water contents of the leaves resulted in a corresponding increase in Pn in general. The increased water content helps in maintaining the turgidity of the assimilatory cells and the proper hydration of their protoplasm. Although the temperature, soil moisture and relative humidity were reasonably high in June and August, the limiting factor for Pn was possibly the low sunshine hours which were found to be less than 2 h d^{-1}.

The effects of PPFD on Pn were only revealed when other environmental variables were taken into account. Smith *et al.* (1993a) did not initially find any significant reduction in Pn at high illuminance but photo-inhibition was only revealed when the nutritional status of tea was taken into account. In Japan, Sakai (1987) estimated photosynthetic light saturation to be between 500 and 1000 μmol m^{-2} s^{-1} PPFD and, in Malawi, Squire (1977) estimated saturation at above 350 W m^{-2} (equivalent to 735 μmol m^{-2} s^{-1}). Such discrepancies are to be expected as nutrition (Squire, 1977; Smith *et al.*, 1993a), season (Squire, 1977; Sakai, 1987) and cultivar (Sakai, 1987) can affect the photosynthetic response to PPFD. However, if the supply of CO_2 is maintained constant, Pn increases with the intensity of light until the maximum is reached.

Humidity is of importance in tea physiology primarily because of its influence in determining the loss of moisture by evapotranspiration. In sugarbeet, Rosenberg (1974) observed a reduction in Pn under low humidity, probably causing rapid evaporation from guard cells and causing stomata to close. Williams (1971a) working on tea in Malawi observed that an increase in atmospheric humidity (reduction in VPD) tends to reduce leaf water stress. In the present study, the highest Pn was recorded in October when humidity was very high; temperature,

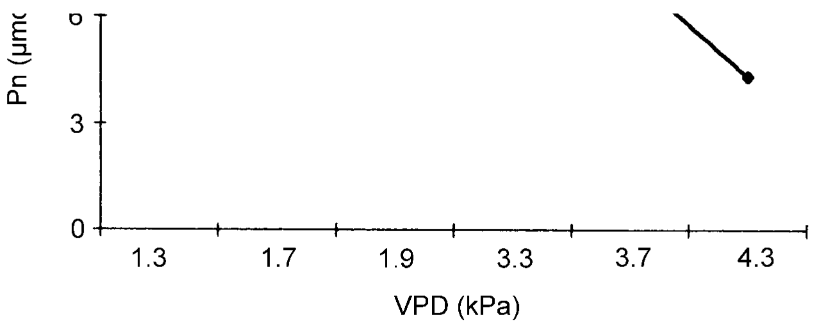

Fig. 3. Effect of vapour pressure deficit (VPD, kPa) on photosynthetic rate (Pn, μmol m^{-2} s^{-1} (7200 observations)). Climatic variables were the same as shown in Table 1 and Fig. 1.

sunshine hours and soil moisture were moderate and PPFD was highest. El-Sharkawy *et al.* (1993) reported similar observations in field grown cassava.

Stomata normally close in response to increasing VPD which is sensed by the leaf (Jarvis, 1980). The responses of Pn become clearer when plotted against VPD (Fig. 3). A linear relationship between ψ_L and VPD observed in the present study is in agreement with an earlier report on tea (Williams, 1971b).

Wind turbulence could be useful in reducing high leaf temperature (35 °C and above) which otherwise would adversely affect Pn (Banerjee, 1993). In Darjeeling, however, ambient temperature never becomes lethally high, therefore its direct effect in reducing leaf temperature is rather minimal. Among the many indirect effects, special mention may be made of transportation of hot and cold masses of air thereby causing fluctuations in temperature, movement of clouds and fog that affects water relations and alters illumination intensity, and evaporation of water from soil and water reservoirs. Mavi (1986) stated that the rate of photosynthesis is lower in calm conditions and higher when the wind is blowing, although a positive correlation is not always observed between wind speed and photosynthesis. In Darjeeling, high wind is associated with the beginning of the rainy season. Throughout the rest of the year the mean wind speed gradually increases from 4 to a peak of 5.4 km h^{-1} in June. The highest Pn was found at a wind speed of 4.2 km h^{-1} in October.

Photosynthesis and yield

The yields of dried tea obtained during the fourth and fifth years after planting (618 and 712 kg ha^{-1} in 1996 and 1997 respectively) showed year to year variation. The difference in yield may be due to the age of the plants. The seasonal yield distribution varies primarily as a result of seasonal changes in temperature and the development of soil moisture stress during the dry season. Kericho in Kenya has the most even yield distribution with only a relatively small drop in production during the dry season. By contrast, both Mufindi, Tanzania, and Mulanje, Malawi, showed marked seasonal variations in yield distribution. For instance, in Mulanje, about 80% of the annual yield from non-irrigated tea may be harvested during the five months from December to April (water surplus period) (Carr and Stephens, 1992). However, in Darjeeling, 50% of the annual crop is produced in the wet season (June to August). The yield development of six contrasting clones from Kenya, Malawi and Tanzania under a range of drought regimes has been studied by Burgess and Carr (1996). During the fourth year after planting, the yield of dried tea from one clone, labelled S15/10, reached 5650 kg ha^{-1} compared with a mean of 3890 kg ha^{-1} from the other five clones. These values are greater than the 3000–5000 kg ha^{-1} currently obtained on the best commercial estates in southern Tanzania and higher than the 618 kg ha^{-1} obtained in the present experiment. The large yields from young tea achieved by Burgess and Carr (1996) in their experimental field at commercial plant densities were possible through rapid establishment of crop cover by pegging, prevention of drought stress by irrigation and the removal of a high proportion of harvestable shoots by tightly controlled plucking.

A proportion of the carbon fixed by photosynthesis is used in maintenance respiration, and the remainder is then available for partitioning into shoot or root growth or into storage reserves (Smith *et al.*, 1993a). If photosynthesis and yield are closely coupled, the highest yield would be expected in October when Pn was observed to be maximal. However, the highest yield was obtained in June (Fig. 2). The temperature (18–23 °C), relative humidity (90–95%) and soil moisture were high during June to August and moderate Pn was observed. Relative air humidity of 80–90% is favourable for growth of tea plants but shoot growth is inhibited and adversely affected if it is below 50% and 40% respectively (Huang, 1989).

The relationship between Pn and yield may be obscured in the young plantation under study (Fig. 4), since the carbon which is fixed contributes both to increasing crop cover and to the production of young shoots. However, there is a clear need for further investigations into the relationship between Pn and yield in established plots of various mature tea clones. Similar views are offered by Smith *et al.* (1993b) with respect to the establishment of a relationship between Pn and yield in young tea plantations.

CONCLUSION

In the Darjeeling Hills, high temperature and irradiance never reach a sufficiently high level to have a detrimental effect on Pn but an important limiting factor for Pn was found to be moisture stress. Low PPFD and low temperature had significant inhibitory effects on Pn.

Large populations of clones are necessary to determine correlations between Pn

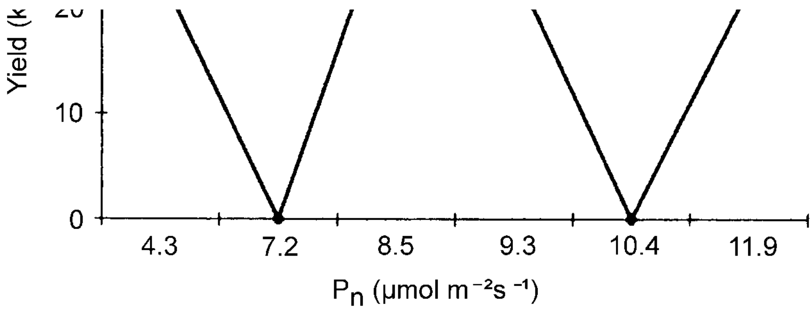

Fig. 4. Effect of photosynthetic rate (Pn, μmol m^{-2} s^{-1} (7200 observations)) on seasonal mean yield of processed tea (kg ha^{-1} (52 rounds)) during 1996 and 1997.

and yield and an attempt is to be made to model the effect of climatic variables on the principal growth processes in order to predict potential and actual yields in different locations.

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